Estimating the commercial trading value of spectrum

A report for Ofcom

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Executive Summary[1]

Scope of the project

This project was commissioned by Ofcom in order to assist spectrum market participants in developing a more widespread understanding of the drivers of commercial spectrum value[2]. The project was not aimed at supporting any particular Ofcom policy development, but rather to provide background information of general relevance to a wide range of spectrum management issues. The broad aims of this study were to provide both an analytical framework, and spectrum valuation models that would establish those variables that drive the value of spectrum. Such ambitious aims were very wide in scope. From the outset, we recognised that in an investigative research project of this nature, deriving an ideal generic spectrum valuation model that could be applied to all frequency bands, would potentially not be possible. As a result, we instead sought to develop a flexible generic framework that would provide insights into the drivers of spectrum value and the potential relationship between the specific circumstances of spectrum users and the spectrum valuations. This objective has guided our approach to spectrum valuation for the purposes of this research project.

Approach

We started from a hypothesis that all spectrum has a generic value, arising from the removal of all constraints except the intrinsic limitations of frequency and bandwidth (i.e. limitations that arise from the working of laws of physics at different frequencies). This starting point is illustrated stylistically in Figure 1, where each purple (light colour) curve shows variation in value by frequency, and the spectrum value hypothetically falls as frequency increases.[3] This reflects the increasing costs of providing radio transmission capacity at higher frequencies for given levels of coverage and traffic. Moving from the origin outwards, curves of rising value are shown to reflect the impact of drivers of value other than frequency. Figure 1 also has an orange (dark colour) line which shows, in a stylised manner, the “observed” values of spectrum which do not vary in a monotonic fashion with frequency. There are discontinuities in these values because some drivers are not continuous (e.g. bands are either harmonised or not) and/or because the combined effects of drivers are not continuous (e.g. bandwidth and technology).

In this project, we sought to understand the factors leading to the observed discontinuities in value and to investigate the possibility of modelling the underlying continuous curves in different dimensions. There is little precedent to call on for this work.

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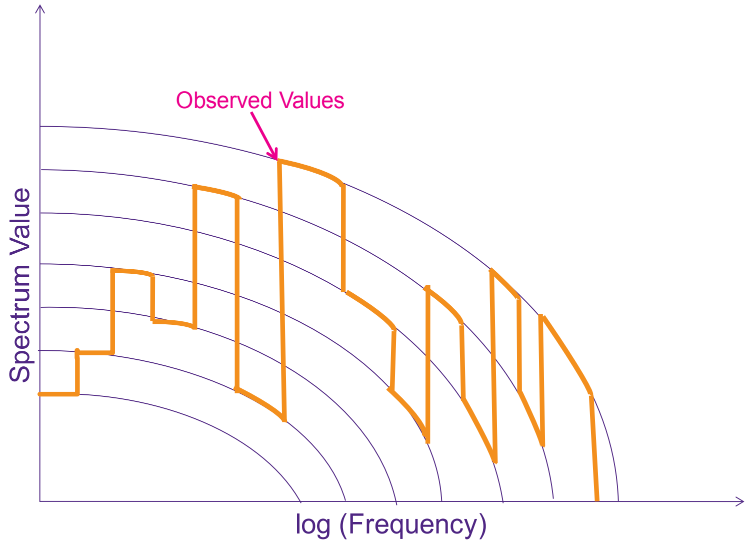
[1] Ofcom's technical research program enables it to keep up to date with technologies and trends, so that it can be in the best possible position to execute our regulatory duties. Ofcom does not conduct research in-house but makes use of external resources, such as private commercial organisations, university departments and government funded research institutions. These reports present the findings of technical work conducted on Ofcom’s behalf. The opinions and conclusions stated within this report are those of the organisations who conducted the research and may not reflect the view of Ofcom or imply any future policy work in related areas. Ofcom is not responsible for the content or accuracy of this report.

[2] This report does not address the economic value of spectrum as measured by the sum of consumer and producer surplus.

[3] Value is also driven by the amount of contiguous bandwidth available to a user but this is not illustrated in the two-dimensional diagram shown in Figure 1.

Figure 1: Stylised view of spectrum value



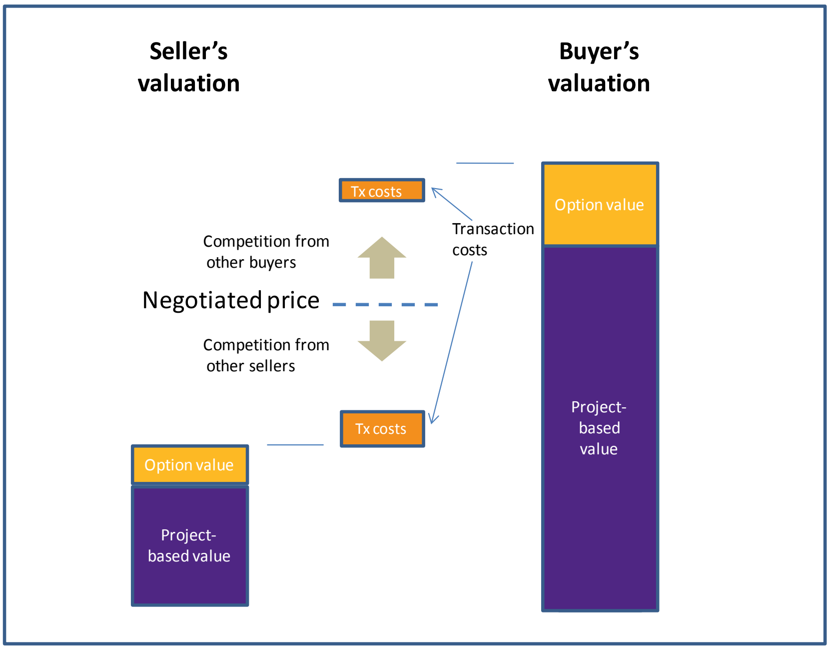
Source: Plum

Sources of commercial value

The value of spectrum to a user comprises the sum of an expected project value (i.e. the net present value of project cash flows) and an option value. The project value may include a defence value arising from protection of monopoly rents; however, effective competition policy will reduce this value. The option value of spectrum is the value to a firm of having the flexibility to invest at the optimal time, where there are irreversible costs associated with making investments, there is the possibility of waiting for new information to arrive and uncertainty over investment returns.

Spectrum market values can be identified in a variety of ways, primarily via observation of auctions and of trade results. In all cases the values obtained reflect commercial project value and possibly also the option value of spectrum. In the case of trades, the transaction costs of buyers and sellers also affect the negotiated value of spectrum (see Figure 2). Sellers' transaction costs in particular may be significant because of their complementary investment in networks and if existing contracts need to be broken, assets may need to be written off and there are risks of loss of business or service continuity (if new equipment or services must be brought into operation). These costs are not easily observed and/or quantified from outside the seller organisation. The differential allocation of information, with some information relevant to value not being fully available to the market, also affects value.

Figure 2: Factors influencing traded price of spectrum

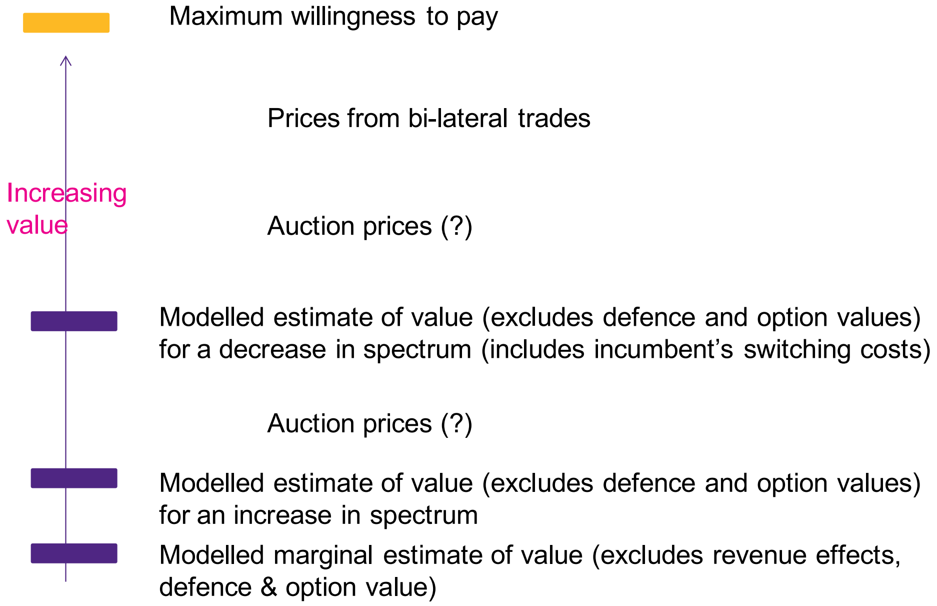


We sought to rank the different methods for measuring commercial spectrum value in Section 2.3, and the results of this analysis are shown in Figure 3. Auction and traded prices include the commercial option value as well as the private project value of spectrum. Option values can be significant but are difficult to calculate and so are not generally included in independently calculated values of spectrum. This suggests third party estimates of traded or auction values could be lower than actual realised values, though traders will also have inside knowledge of risks and costs not known to third parties and this may also affect their estimates of commercial value.

Values from an auction can be lower than those achieved in bi-lateral trades (assuming trade occurs) because in an efficient auction, the spectrum either sells at the seller's reserve price (which can reflect the seller's own estimate of its project plus option value) or (depending on auction rules) at the highest losing bidder's price. In a bi-lateral trading situation, competition from losing bidders is absent and the buyer may not know the seller's reserve price, in which case the seller can hold out for a higher price than would have resulted from an auction. Hence if spectrum buyers use auction values as a benchmark for a fair traded price, this may result in them holding out for an unrealistically low price – in these circumstances, where transactions costs create temporary monopsony/monopoly bargaining positions, trades may fail to occur.

Spectrum value also depends on the block size being considered; sometimes a larger block size will result in larger average values/MHz, assuming all else is equal, where contiguous bandwidth is important for the efficient use of the spectrum capacity concerned. Trades could easily be for more than marginal blocks of spectrum, and so any modelling of value should have the facility to vary the block size.

Figure 3: Hierarchy of measures of spectrum value



Modelling approach

When designing our approach, we considered whether it was possible to construct a service-neutral model of spectrum value. We concluded that this was not possible, because the value of spectrum in a given frequency band is to a large extent determined by network structures and final communications markets, both of which are service-specific. We suggest that most commercial wireless services can be characterised as requiring one of four network types – cellular mobile, fixed point-to-point, single site mobile and broadcast networks. Our conclusions from examining these cases are given below.

Cellular mobile

Value drivers

Within the 300MHz-3GHz frequency range, the commercial project value of spectrum to a Mobile Network Operator (MNO) is determined by the NPV of expected revenues less costs; therefore the primary value drivers are revenue and cost drivers.

Revenues will depend on demand for the services offered and their price, which in turn are driven by economic variables such as income and competition from other (substitute) services and other operators (and their relative price and service quality). In practice, revenues are often modelled by assuming a forecast growth in ARPU and subscriber numbers with little dependency between these variables because future income and demand elasticities for new services are not well understood. The value of spectrum to a licensee is governed by their expectations about the future values of these revenue drivers. While there are sometimes common views across the market of the values for revenue drivers and of the impact of factors such as income growth and population growth, and while competition will lead to some similarity in service offerings and coverage, it is clear that some of the variables will be operator–specific, particularly the assumptions of traffic and market shares. In addition, roaming revenue can depend upon the extent to which the additional spectrum is harmonised internationally for mobile applications as well as commercial strategies and regulatory policies.

Cellular mobile costs are comprised of infrastructure (or network) costs, marketing costs (mainly handset distribution and subsidies) and administrative costs (e.g. billing). Administrative and non-handset related marketing costs will affect the overall level of prices and so service demand and viability, but they do not tend to vary with spectrum frequency. However, infrastructure and handset subsidy costs do vary according to the frequency band under consideration, depending upon the degree of harmonisation, the extent to which lower frequencies enable longer range and fewer sites and the extent to which increased subscriber capacity per site can enable an overall reduction in the number of sites.

Modelling approach

Both revenue and cost drivers are affected by the existing assets held by an operator. Revenue assumptions depend on the market positioning and market share of the operator. Cost assumptions depend upon the existing spectrum held by the operator and its historic investment in sites and handset subsidies. Our approach to estimating spectrum value for cellular mobile operators started with the development of a comprehensive model to assess project-based mobile cellular business propositions. This model calculates the NPV of potential uses of the spectrum while considering these revenue and cost drivers.

Many of the parameters in this model depend upon the precise characteristics assumed for a licensee. This means that the calculated commercial value of spectrum from the model will be dependent on assumptions about the average or marginal user input into the model. Confidence in the values applied to these parameters is therefore essential to have confidence in the results. While some modelling assumptions can be made with reasonable confidence based on available data (e.g. unit equipment costs), others are reliant on the current assets and operations of each MNO, market forecasts for the mobile sector and assumptions about the sources of new revenue streams. With few existing MNOs, the existence of commercially confidential data, and considerable variability in market share and nature of their subscriber usage, it is difficult to derive a single set of typical assumptions from available data that is representative of all MNOs. It is not possible to present meaningful typical or generic values without making assumptions about all these factors and to do so could be misleading. Therefore we have used the cost reduction scenario alone to illustrate the general importance of different drivers in value, but the results obtained cannot be interpreted as being estimates of the value of spectrum to a particular MNO in a particular market situation.

Results

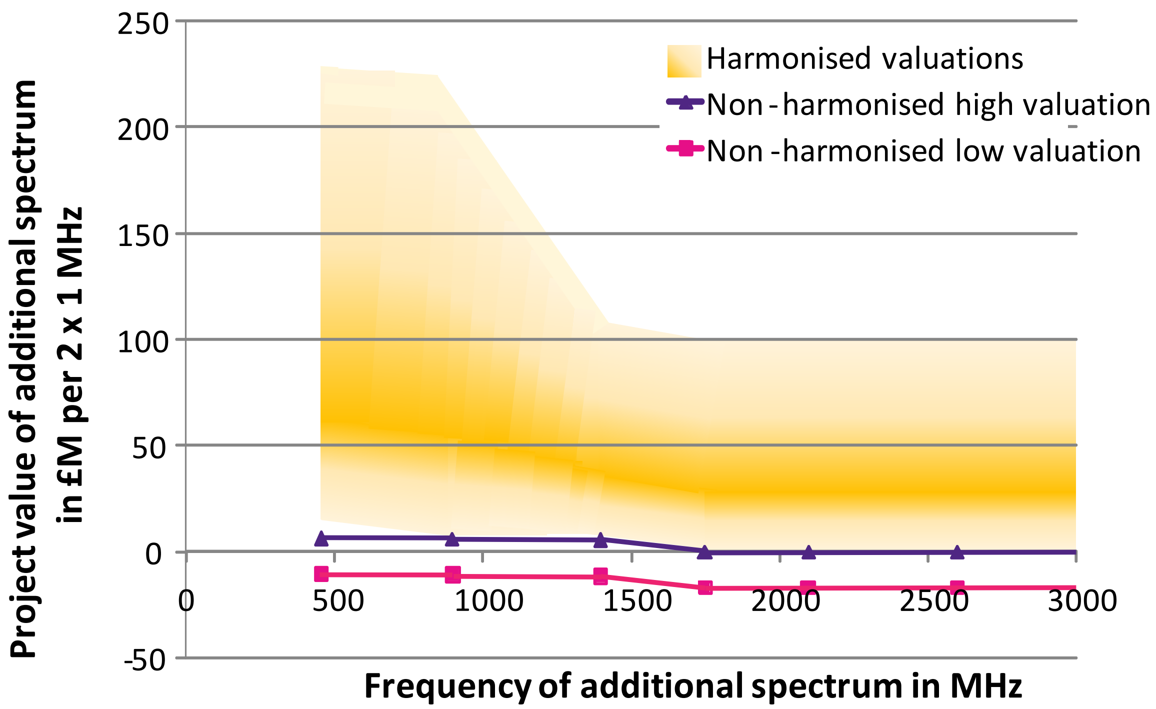
To evaluate the potential for value arising from cost savings attributable to spectrum holdings, we considered an hypothetical 3G network enhancement where an operator intends to increase the subscribers on its network over the next 10 years from a starting level of 5 million subscribers growing linearly to 7.5 million. We investigated the impact on spectrum value[4] whilst varying key parameters such as the existing band of operation, the quantity of the assumed existing spectrum holdings, subscriber growth, usage growth and the degree of in-building penetration. The additional harmonised spectrum acquired to achieve the hypothesised network enhancement was varied over a frequency range of 460 MHz to 3000 MHz. In addition, the potential project-based values of additional non-

[4] Calculated as an NPV of cashflows over a 10 year period. A 10 year period was chosen because market conditions beyond this period are often considered by operators to be too uncertain to include in commercial valuation.

harmonised spectrum were also estimated, by inflating network and user terminal costs caused by the resulting lack of scale economies in production. The resulting spectrum values are given in Figure 4, where:

- The two parallel lines give values of an additional 2x5 MHz of non-harmonised spectrum to achieve a hypothetical network enhancement to an operator that has already 2x10 MHz of 1750 MHz spectrum in our middle traffic/subscriber scenario[5].
- The shaded area gives the range of values we have obtained for 2x5 MHz of spectrum that is assumed to be harmonised and where we vary assumptions about existing holdings, future subscriber and traffic growth and degree of in-building penetration.

Figure 4: Estimated values for incremental 2x5 MHz for a cellular mobile operator (expressed in terms of average value per 2 x 1 MHz)



Source: Plum analysis

The results show spectrum values ranging from zero to £240M per 2 x 1 MHz based on an evaluation period of 10 years and depending upon the input assumptions. Under the low case assumptions, non-harmonised spectrum value for cellular mobile applications is negative, although under the high case assumptions there is a significant positive value. This illustrates the reliance of the mobile industry on spectrum harmonisation when seeking new bands for advanced services. When used for coverage enhancement, the analysis suggests that, under the low case assumptions, non-harmonised spectrum could still have value where the additional spectrum available is at lower frequencies than existing spectrum holdings at 1750 MHz.

[5] Subscribers are assumed to grow from 5m to 7.5m in 10 years. Data usage per user in the busy hour is assumed to grow from 20kbit/s to 100kbit/s after 10 years.

Varying other individual parameters across reasonable bounds for harmonised spectrum results in a wide range of values. At the higher end of the frequency range where benefits arise from capacity enhancement, values vary from zero to £100M per 2 x 1 MHz The range of values is even greater at the lower end of the frequency range where coverage enhancement (in particular in building penetration) is the major driver; values here vary from £10M to £240M per 2 x 1 MHz. Varying more than one parameter simultaneously could be expected to introduce even greater variability.

Conclusions

Although it is possible to model cellular spectrum value, the adequate capture of important value drivers requires complex models and a large number of input assumptions.

- Some assumptions can be made with reasonable confidence (e.g. unit equipment costs).
- Some assumptions are reliant on the current assets and operations of the specific MNO (number of sites, subscribers and usage per subscriber). With few existing MNOs, the variability in market share and the nature of their subscriber usage, there is not a single set of typical assumptions that is representative of all MNOs.
- Other assumptions are reliant on market forecasts for the mobile sector (ARPU growth and traffic growth). Forecasting mobile services over the long economic lives of the network assets driving spectrum values is necessarily uncertain, and relative spectrum values will therefore depend upon the respective aspirations and market confidence of individual operators.

Our results that rely on assumptions in the first two categories show a wide range of project-based spectrum valuations, but this is the same case for any buyer or seller in the market when assessing each other's potential valuations. However, buyers and sellers may may in time know each other's identity and so characteristics in terms of frequency holdings, market share etc, in which case a narrower range of values than those given in Figure 4 could be established based on the type of modelling we have undertaken. However, generic modelling of spectrum values for cellular mobile purposes will remain very uncertain and not indicative of specific circumstances.

Fixed point-to-point

The value of spectrum used by a single fixed point-to-point link is difficult to determine with any precision as it is specific to location / route and the demand associated with that location / route. We have therefore valued spectrum for fixed links assuming the spectrum is managed by a hypothetical commercial band manager. The focus of this work has been on bands where excess demand is thought to exist, i.e. those below 20 GHz.

Modelling approach

The approach we have used assumes that the value of spectrum currently being used by fixed links is related to the additional costs incurred in moving towards an uncongested (i.e. typically higher) frequency band.[6] Those additional costs mainly relate to some links requiring an additional hop because of less benign propagation conditions in the higher frequency band. The value of a particular band to the hypothetical band manager is the cost of migrating its fixed links to another band including the opportunity cost of purchasing spectrum for the second band. The value of the second band is

[6] Data we have used is based on the current link length distribution though we recognise this may be changing as fibre may be a substitute for some long backbone links.

given by the cost of migration of its links to a third band plus its opportunity cost, and so on to a point where no excess demand (opportunity cost) is foreseeable in a frequency when the spectrum price is zero. Therefore we can build up the value of a band using a model of successive displacement and aggregating the values accordingly. In practice, when we look at a whole band the additional costs of moving to the next band will be an average across all links, as not all links will require extra hops when the frequency band changes.[7]

In applying this framework we have analysed the link population in the different frequency bands in terms of link length, availability and required received signal level. On this basis we have identified the number and types of links that would require an additional hop when moving up a frequency band. These have been costed based on the additional equipment, site and maintenance required.

The analysis shows that the maximum path lengths achievable in the lower frequency bands (1.4 to 6 GHz) are broadly the same and therefore no double hops are required when moving to the next highest frequency band. This implies that the value of the spectrum is broadly the same across in these bands.

The largest number of double hops required occurs in the move from the 7.5 GHz band to the 13 GHz band. This is not surprising as this is the largest relative frequency gap[8] between adjacent available frequency bands. Coincidentally it is between these frequency bands (at around 8 GHz) that equipment becomes less expensive when moving up in frequency, thereby offsetting some of the costs of additional hops and hence moderating the incremental value of the lower band (7.5 GHz).

Results

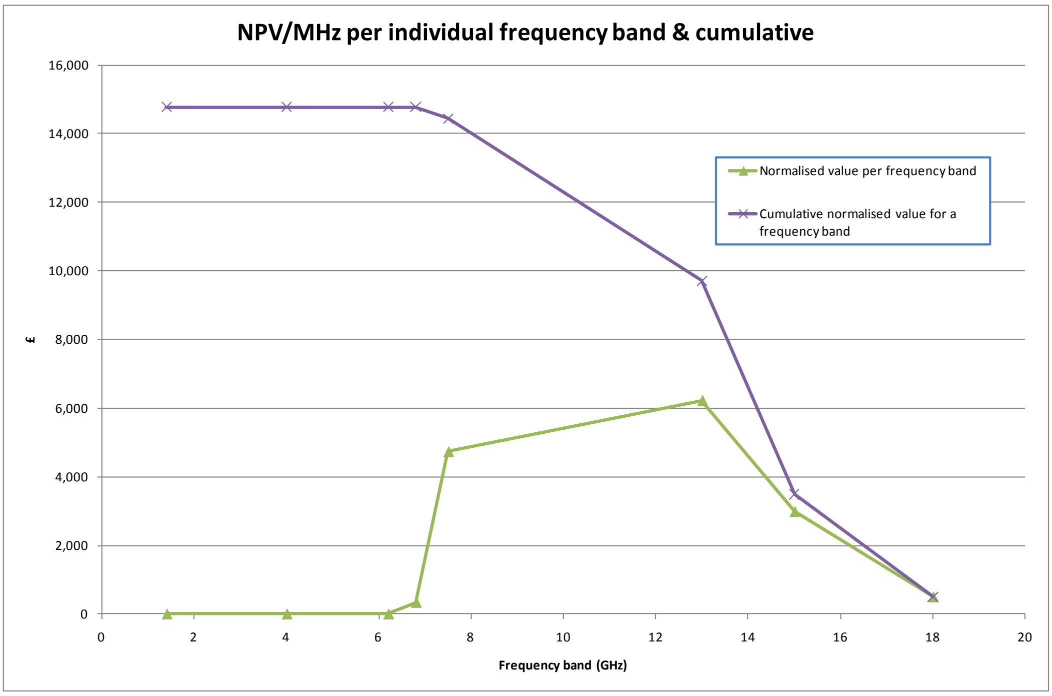
Application of the method summarised above gives the following results by calculating the NPV of cashflows over a 15 year period:

- In the case of spectrum that is already congested, the value estimates fall in the range of approximately £35k/MHz for the 1.4 GHz to 7.5 GHz frequency bands and declining to around £1k / MHz for the 18 GHz band.
- For new spectrum that is harmonised, the value estimates fall in the range of almost £15k/MHz for the 1.4 GHz to 7.5 GHz frequency bands and declining to around £500 / MHz for the 18 GHz band. The value is less than that for already congested spectrum because the new band takes time to fill (see Figure 5).
- In the case of new spectrum that is not harmonised, we show that there is no positive value since the additional equipment cost is significantly greater than the value of the spectrum when harmonised.

[7] Also in practice the transaction costs of moving mean that links in higher frequency bands do not automatically migrate to lower bands when suitable spectrum capacity becomes available.

[8] Notwithstanding the 1.4 GHz to 4 GHz gap but there the services in the two bands are rather different.

Figure 5: Value per MHz for additional spectrum



Source: Plum analysis

The values above can be compared with a recent Ofcom auction result (10 GHz) and with Ofcom's AIP fees, noting that the latter are half or less than half of the estimated opportunity costs calculated in 1998. It is found that the 10 GHz auction value is significantly lower than the derived value. However, in addition to the general variability of market conditions, there are three important factors specific to this auction that are likely to have suppressed the auction value concerned: MoD use in the band as a constraint, an equipment cost premium, as manufacturers do not regard the band as fully harmonised, and the cost of the user managing the band. In terms of comparison with AIP values expressed in equivalent NPV/MHz values, the values we have obtained are approximately double the equivalent AIP values. This is broadly consistent with the fact that AIP fee rates were was set at half or less the calculated opportunity cost in 1998.

Conclusions

From the exercise in valuing spectrum with respect to fixed links we conclude that:

- Other things being equal lower frequency bands can be more valuable to a hypothetical commercial band manager at a particular point in time, assuming that they are congested and consequently that there is currently significant unmet market demand to be fulfilled for links with long paths.
- The valuation does not correspond at all closely with the single Ofcom auction result, but there are good reasons for this, underlining the inapplicability of individual auction results as benchmarks for general spectrum valuation purposes when specific circumstances pertain.
- The valuation corresponds more closely with Ofcom's AIP fees.
- Non-harmonised spectrum for fixed links could have little or no value.

To achieve greater certainty in the valuation it is clear that more detailed information is required regarding the unmet demand profile projected over the lives of the network investments concerned at different times in particular bands, not only in terms of extent of demand but also in terms of lengths of paths and their geographic distribution. For example, over the last 15 years demand for spectrum to provide fixed backhaul has changed in ways that were not anticipated partly because of rapid growth in demand for cellular mobile services. Furthermore, insight is required regarding user choices in respect of whether to use fixed links or a wired alternative, how these choices might be made when vacating spectrum over time and users' demand responses to variations in spectrum price signals.

Single site deployments

Private Business Radio (PBR) users are distributed through towns, cities and rural areas in the UK where use of the spectrum fulfils a business need for communication between employees. Licensees generally have a local region of desired coverage, corresponding to the area in which they undertake most of their business. PBR licensees' choice of frequency band (generally between VHF and UHF bands) will typically be dictated by operational needs and operating costs. Some may prefer UHF spectrum because of the need for hand portable terminals, and some may prefer VHF spectrum to reduce deployment costs. Because there are many small users in PBR bands, our approach to valuing spectrum for this general type of service is based on the value that might be extracted by an hypothetical commercial band manager rather than via spectrum managed by the regulator (as now).

The availability of mobile phones or, for some users, licence-exempt PBR provides alternatives to the use of licensed PBR spectrum. However, licensed PBR is usually preferred over these alternatives because of its bespoke nature and the certainty it gives over the associated business communications costs. The higher value placed on PBR was also apparent in the willingness to pay research undertaken by the Radiocommunications Agency in 2000. This estimated consumer surplus for PBR licensees at £95 / terminal / month. This surplus provides a measure of a users' maximum willingness to pay for the service. While changes in relative PBR terminal costs and mobile communications alternatives may mean this estimate is out of date, it is used to illustrate the valuation method we use.

Modelling approach

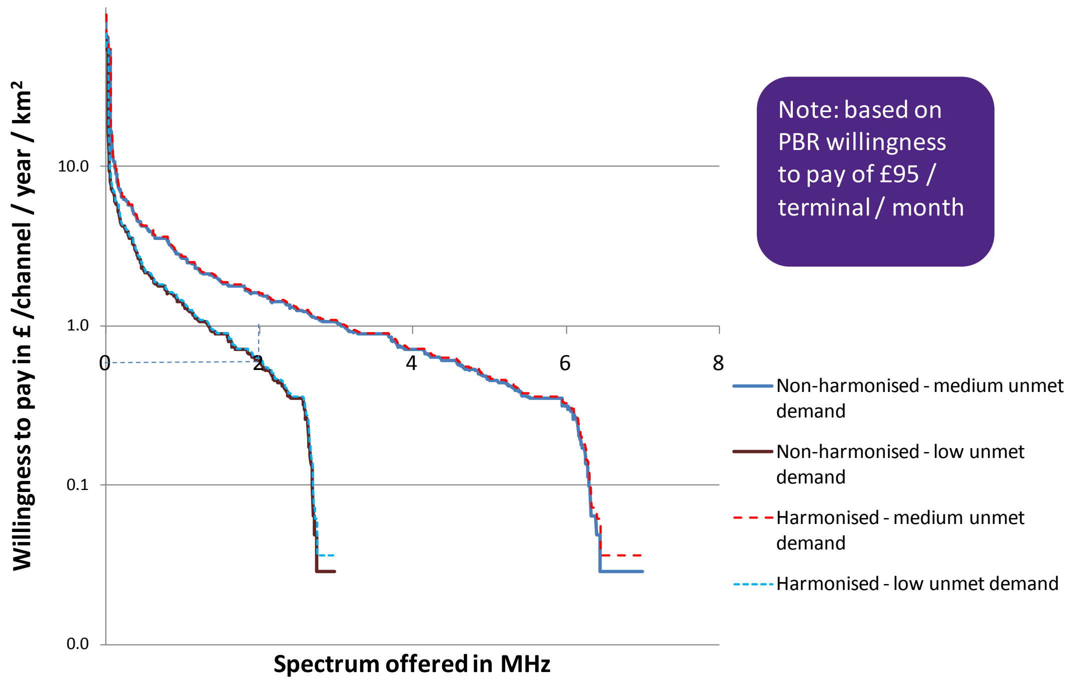
Spectrum suitable for PBR has a commercial project-based value only in areas of excess demand. Analysis of the existing assignment data showed that within the UK only the greater London area is currently very congested for PBR though it is possible excess demand could occur outside London in time. In greater London there is excess demand in both VHF and UHF bands and the data implies considerable excess demand for VHF channels. The project-based marginal commercial value of additional spectrum is given by what a commercial band manager would be able to charge users per km^2 based on the number of channels and exclusion area they occupy. Assuming that the excess demand exceeds the capacity of the marginal amount of additional spectrum concerned (e.g. an additional 2x12.5 kHz channel) and that users with the highest willingness to pay gain access to the new spectrum, the maximum that a commercial band manager could charge for the spectrum is given by the marginal willingness to pay of PBR users less any additional costs they face as a result of the marginal spectrum addition concerned (such as higher equipment costs to use non-harmonised spectrum or increased deployment costs arising from the use of higher frequencies).

Results

Using a notional baseline 2x2 MHz of additional "new" spectrum to illustrate the value, we estimated the annual value of VHF spectrum to be £0.60 / MHz per km^2 for 10,000 km^2 in Greater London (see Figure 5). The use of harmonised or non-harmonised spectrum did not make a significant difference to this value. This translates to an NPV over 10 years of £2.8M for the 2x2 MHz block within this area. It should be noted that this estimate does not include the costs of spectrum management which would tend to reduce the commercial value. It further assumes that demand for PBR services is static over the 10 year period. A forecast for positive future growth in demand for PBR would enhance the value of the spectrum.

The value of a UHF block was substantially lower since users would incur higher deployment costs to use an increment of spectrum. It is estimated at £0.30 / MHz per km^2 per annum or £0.35M for a 2x0.5 MHz block of the same geographical area. We found that existing excess demand in this area at UHF can all be met by an additional 2x0.7 MHz of spectrum. We note that this means it does not make sense to gross the value up to a 2x2 MHz block, as spectrum beyond 2x0.7 MHz is likely to have a much lower value in the short term. As for the VHF analysis, the estimate does not include the costs of spectrum management and assumes that demand for PBR services is static over the 10 year period.

Figure 5: PBR current commercial willingness to pay per km^2 per annum as a function of the amount of VHF spectrum offered



Source: Plum analysis

Conclusions

The values can be compared with existing AIP values previously calculated for the PBR bands although they should not be expected to be the same. Although there is no distinction between AIP charges at VHF and UHF, the values are nevertheless broadly similar to the value we calculated for VHF. The one market benchmark for the auction of 2x2 MHz in the UHF spectrum band was £1.5M which is higher than our estimated value of UHF spectrum. However the single auction price was for a longer duration and may include option values and be based on more optimistic PBR growth assumptions.

The methodology is made possible by the large numbers of assignments in the VHF and UHF spectrum bands. However, the methodology could be improved by:

- Updating the estimate of willingness to pay for PBR. The values used in our analysis were derived in 2000 and are very likely to be out of date.
- A better understanding of how the extent and profile of demand may be changing over time. Excess demand was calculated based on the existing profile of demand within the London area alone.
- Greater scrutiny of the precise assignments to better understand areas excluded and packing densities.

In contrast with other broad application groups such as cellular mobile and broadcasting, there is a large degree of homogeneity between the individual transmitter deployments, equipment used and modelled commercial benefits obtained from the use of the spectrum. The large number of individual users enabled a more statistical approach to be taken.

Broadcasting

We have found it difficult to derive general estimates of the value of spectrum for broadcast networks. The reason for this is that the value of the broadcast platform using radio spectrum to individual broadcasters is specifically related to the content proposition, competing content propositions, the costs of content and content and coverage regulation that apply to each of them in a way that does not apply to fixed and single site networks, and that is less acute for cellular mobile networks. In these other cases individual buyers/sellers can make direct infrastructure-spectrum trade-offs that provide a useful indication of value.

In the case of TV broadcasting using licensed digital terrestrial multiplexes the configuration of the transmission infrastructure has historically determined the embedded base of consumer equipment, which means it is costly to change the infrastructure deployed in UHF frequencies and still maintain service reception to meet particular coverage targets. Realistically, co-ordinated actions across a number of (and possibly all) national multiplex operators is required to release spectrum at a reasonable cost/MHz and meet commercial coverage levels (of 80%). However different considerations could apply when incremental spectrum is brought into use (e.g. following Digital Switchover). A similar situation applies in respect of local radio where changes in spectrum use may only yield commercially attractive blocks of spectrum if all broadcasters adjust their spectrum use.

Recent auction values suggest the value of UHF spectrum is low at the margin but this could be result of the current economic conditions and the prospect of increased supply from the digital dividend. While it may be possible to derive alternative commercial values for spectrum which is not subject to existing content restrictions, we have not sought to do so in this project.

Overall conclusions of the study

Our analysis has yielded a range of illustrative commercial value estimates from our models based upon a variety of hypothetical assumptions, designed to exemplify the methodological approaches to spectrum valuation that could be employed in different circumstances. More certain estimates of value in specific actual situations would be possible if there were better information available on the characteristics of the existing networks and users and on unmet demand. This would enable more realistic consideration of the real-world choices facing particular spectrum users and so a better understanding of how they might value spectrum for commercial purposes in different circumstances.

While there are many caveats on our estimates of commercial spectrum value we find that:

- The potential value is greatest from cellular mobile applications, followed by PBR and then fixed links. Regulatory constraints currently prevent equivalent approaches to the commercial valuation of UHF spectrum for broadcast purposes. There are orders of magnitude differences in value between these applications.
- In general, use of spectrum has more value for mobile applications than for fixed applications, in part because there are fewer alternatives for the former. This means that there are breakpoints in spectrum values at frequency ranges where mobile applications are not technically feasible because good non-line of sight coverage is not possible. Although the development of new technology and harmonisation will move these breakpoints over time.
- Although the quantity of spectrum supply for a particular application is important, it is not the main determinant of spectrum value. The frequency range under consideration and the degree of harmonisation are also influential.
- For each of the applications we examined higher values are typically associated with lower frequencies, within a group of harmonised bands.
- Harmonised spectrum is more valuable than non-harmonised for cellular and fixed links applications, while it is less important for PBR which has historically been a niche market using non-harmonised equipment. The benefits from harmonisation that we capture are primarily those arising from lower equipment costs that can be enjoyed by exploiting scale economies in production. Although harmonisation can also impose costs and may be disadvantageous in some circumstances these are not explored in this study.[9]
- Harmonisation is particularly important to the cellular mobile applications since the sector is reliant on international scale economies in handset and network equipment supply. Leading markets face higher first mover implementation costs where they attempt to utilise non-harmonised spectrum.
- Harmonisation is also important for fixed links applications. Although a wide variety of bands are supported, there is supplier reluctance to support frequencies outside this set of supported bands.

We also find that comparisons between auction values, our illustrative calculated values and the AIP charges that have historically set by Ofcom for spectrum management purposes is problematic. Aside from differences in timing (and so market situations) and the underlying purposes of the different valuations, the following factors need to borne in mind:

[9] These issues are considered in http://www.ofcom.org.uk/research/radiocomms/reports/framework/harmonisation/

- When spectrum that is auctioned is incremental to existing holdings, it is likely to have a lower value (as it will be some time before it is used) than existing holdings, all else being equal.
- Some spectrum requires management by Ofcom, and some spectrum is managed by users. Because Ofcom does not set a separate charge for its spectrum management activities, this means that prices for managed spectrum would be expected to exceed those for spectrum that is sold to the market to manage, all else being equal.
- Technical limitations and coordination requirements can significantly affect market value.
- Regulatory conditions differ between frequencies – particularly those relating to harmonisation and other technical restrictions – and this can have a significant impact on relative values.

The original purpose of this study was to analyse the drivers of spectrum value in order to assist spectrum market participants understand the value of the spectrum they hold to potential third parties with whom they might trade. The wide range of value estimates we obtain could be interpreted as indicating that spectrum owners will have difficulty in assessing the value of their holdings to others and that this might form a barrier to trade. They might underestimate the value and so not offer spectrum for sale or might hold out for unrealistically high prices. However, in an actual trading situation market participants should have better information than was available to us. We used publicly available information but traders could also have private information concerning the value they and others place of spectrum use. In some cases Ofcom could also improve the supply of information by making data on the extent of demand/usage in bands publicly available.

Finally we note that the value of resources is highly uncertain in many markets (e.g. minerals, oil, land, traded stock) and this does not appear to unduly inhibit trading. In these cases information flows are often aided by intermediaries e.g. brokers or private auctions may be held. We are not aware of brokers being active in the UK market but this has occurred on a small scale in the US where spectrum that has been auctioned is now tradable.

1 Introduction

1.1 Objective

This project was commissioned by Ofcom in order to assist spectrum market participants in developing a more widespread understanding of the drivers of commercial spectrum value[10]. The project was not aimed at supporting any particular Ofcom policy development, but rather to provide background information of general relevance to a wide range of spectrum management issues.

Ofcom considers that one potential impediment to trading is that commercial buyers and sellers could have insufficient information on the private value of their spectrum assets to others and that a more widespread understanding of the drivers of commercial value could assist trading by setting price expectations at appropriate levels in particular secondary market situations.[11] By having an appreciation of the potential value of spectrum, owners of spectrum rights may be stimulated to investigate the potential for trading with buyers, and buyers may be encouraged to approach potential sellers. An understanding of the drivers of commercial spectrum values at any time might also provide additional evidence that Ofcom could use in formulating its own spectrum management policies, although how this is done will always need to be carefully considered on a case-by-case basis as regulatory and commercial objectives may not always align.

The aims of this study were to:

- Provide an analytical framework that informs and assists an assessment by those holding or interested in acquiring spectrum access rights based on variables that drive the commercial value of spectrum.
- Construct a generic formula for the estimation of commercial spectrum value based on parameterisation of frequency band and service characteristics.
- Develop a model of commercial spectrum value that implemented the generic formula and assigns values to each of its coefficients.
- Refine the scope of the work in terms of bands, technologies and services to be assessed. As much of the spectrum should be included as is practical.
- Use the model to estimate spectrum value across bands.

Such ambitious aims are potentially very wide in scope. It was recognised from the outset that in an investigative research project of this nature it may not be possible to derive the ideal of a generic spectrum valuation model that could be applied to all frequency bands. However, we have sought to develop an analytical framework that provides insights into the drivers of spectrum value and how valuations are related to the specific circumstances of spectrum users. This understanding guides our approach to commercial spectrum valuation.

[10] This report does not address the economic value of spectrum as measured by the sum of consumer and producer surplus.

[11] The general issue is discussed by Crocioni (2008) http://www2.warwick.ac.uk/fac/soc/wbs/research/cmur/pubs/research_papers/2008/

1.2 Reasons why trade might not occur

Given a key motivation for this work is to consider commercial spectrum value in the context of trading and potential barriers to trade, we briefly set out in Table 1-1 possible reasons why trade might not occur and how information on spectrum value might reduce barriers to trade. As can be seen, information relating to spectrum value could address a number of potential barriers to trade.

The types of information relating to spectrum value that could be useful include

- An explanation of the relative and absolute importance of the key drivers of spectrum value.
- The relative value of different frequency bands.
- The absolute value of different frequency bands.
- An assessment of how policy, technology and market changes affect these values.

Table 1-1: Reasons for no trade and the way information on value might help

Reason for no trade	Description	Use of information on spectrum value
Initial position commercially stable	The value of spectrum to potential seller/s is higher than to potential buyer/s. In this case a commercially stableallocation exists and trade would be inefficient for the potential participants. Value should be thought of both in terms of the expected commercial value of use or potential use and also option values to utilise spectrum in future.	Information could reduce uncertainty and option values and so improve the efficient assignment of spectrum
Information asymmetry (buyer-seller)	Potential buyers value the spectrum more than potential sellers, but the parties either do not approach one another or cannot agree a price for trade. This situation is inefficient and can arise in thin markets with information asymmetries over value (firms are not price takers) and/or where it is costly to find potential trading partners (e.g. because there is no clearing house for trades and/or no public information on who owns what).	If buyers and sellers are informed about the likely value then they might be more likely to approach one another and to trade.
Information asymmetry (agency problems)	There are potential agency problems between owners and managers amongst sellers and/or buyers of spectrum. In particular managers may wish to continue owning spectrum to keep the current business in operation even if it is not the highest value use of spectrum.	More information might help align managers' and owners' interests by revealing to owners the potential traded value of the spectrum and thereby facilitate efficient trade.
Strategic concern	Potential buyers are inhibited from revealing too much information about themselves and their plans and are therefore reluctant to trade, particularly if trade involves greater information disclosure than acquisition of spectrum in primary markets. Primary markets for spectrum tend to be preferred because good information is made available by Ofcom, transaction costs may be lower, large blocks are offered and competitive awards tend to have good price revelation during the award process.	More information could promote or inhibit trade. The latter might occur if the information is gathered from market participants or is revealed by transactions that market participants would prefer to remain private.
Regulation	There are regulatory barriers to trade.	More information might make the cost of the barrier more transparent, and therefore increase the likelihood of a policy or regulatory change.

Anti-competitive	Potential sellers wish to foreclose the market by holding on to scarce resources such as spectrum.	More information on spectrum value might make no difference, or might possibly make dominance and efforts to foreclose the market more transparent.

1.3 The starting point

To motivate variations in value we started from the premise that spectrum has a generic value, arising from the removal of all constraints except the intrinsic limitations of frequency and bandwidth. This is illustrated stylistically in Figure 1-1 where the curves show variation in value by frequency, with the value hypothetically falling as frequency increases, reflecting the increasing costs of providing radio transmission capacity for given levels of coverage and traffic. Curves of rising value are shown reflecting changes in drivers of value other than frequency. Possible other drivers include the size of the final communications market, whether the band is internationally harmonised or not (which affects costs and revenues), type of service provided, size of the spectrum band and so forth. Figure 1-1 provides a very simplified view, as in practice values may not increase monotonically with changes in the drivers and there could be complex inter-dependencies between drivers including frequency.

Figure 1-1: Stylised spectrum value curves

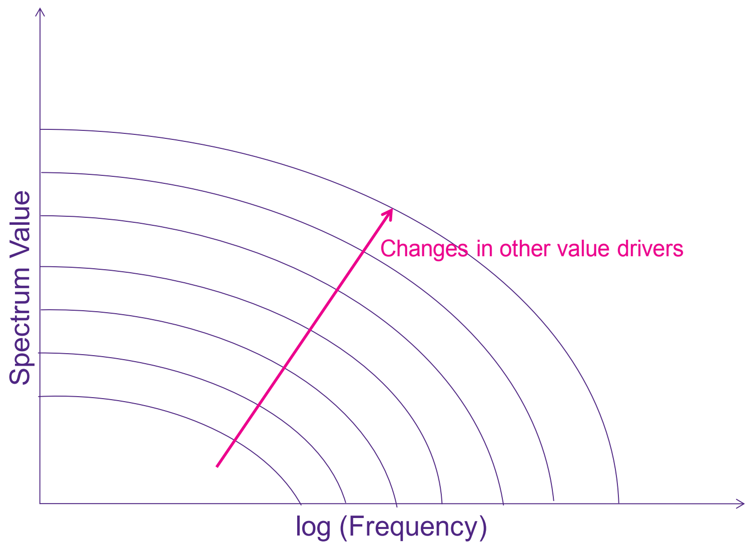
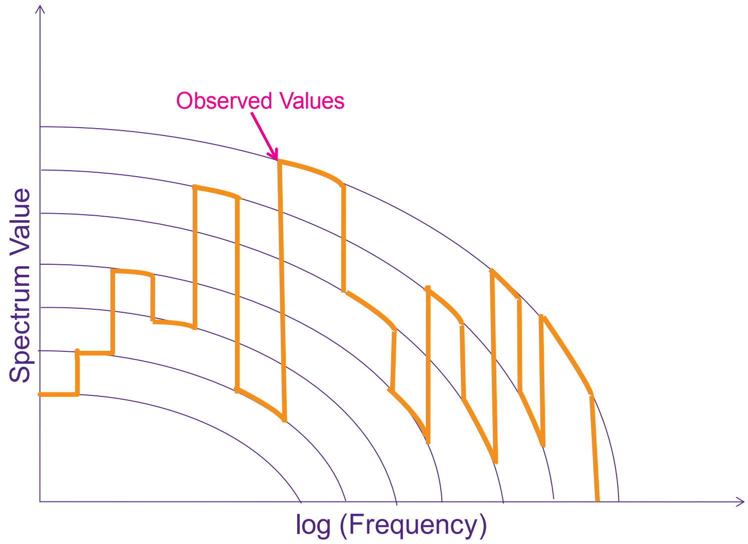


Figure 1-2 also has a darker (orange) line showing in a stylised manner “observed” values of spectrum which do not vary in a monotonic fashion with frequency. There are discontinuities in these values because some drivers are not continuous (e.g. bands are either harmonised or not) and/or because the combined effects of drivers are not continuous (e.g. bandwidth and technology).

Spectrum auctions have revealed a wide range of values that fluctuate over time for bands used for mobile, broadcasting and fixed wireless applications. The difficulties in making like for like comparisons between frequency bands and between market values revealed in different countries and different points in time are well known. Some differences can be partly reconciled by using econometric analysis to adjust for factors such as geography, demographics and GDP (as a proxy for revenue/user). Other factors relating to the local competitive environment may require deeper consideration of a licensee’s business case to obtain tighter reconciliation.

Figure 1-2: Stylised view of observed spectrum value



In this project we are seeking to understand the factors that lead to the observed discontinuities in value and whether it is possible to model the underlying continuous curves in different dimensions. There is little precedent to call on for this work.

When buying spectrum rights (through auctions or trades) organisations will use financial models to estimate the value of these rights. These models are highly specific to the organisation and the frequency range and sale under consideration. More general models have been developed by regulators seeking to set administratively determined spectrum prices for specific services using specific frequency bands and for a "typical" user. These prices are intended to reflect the opportunity cost of spectrum. Both types of values are generally expressed as a function of the following variables:

- A factor "X" which indicates the opportunity cost per MHz km^2 for a given band and location.
- The amount of spectrum used (bandwidth and area sterilised which is sometimes proxied by power).
- The type of service supplied.
- The frequency band (with higher values in bands that are internationally harmonised, that offer better propagation characteristics and that are more likely to be congested).
- The location of use with higher values in more congested areas e.g. higher values in urban versus rural areas.

The factor "X" is either derived in an ad hoc fashion (i.e. judgment and/or historical precedent) or is derived based on one or more of market benchmarks and/or the costs faced by users when denied access to a small amount of spectrum. The key point is that the value estimates are typically not built up from a general model of spectrum value – rather they are band and service specific.

This approach gives the "cliff edges" in value shown in Figure 1-2 and which the Independent Audit of Spectrum Holdings[12] suggested should be replaced by a service neutral per MHz price which reflects a spectrum value curve and propagation characteristics, albeit subject to the value impacts of any relevant restrictions (e.g. binding international harmonisation).[13] One purpose of this project is to explore whether the "generic pricing" approach recommended for regulatory pricing purposes by the Independent Audit is ever likely to reflect market reality in terms of commercial spectrum valuations, although it was not the purpose of the work to examine the implications for regulatory AIP policy.

1.4 Approach

Our approach has been to start (in Section 2) by considering how the commercial price of spectrum might be determined in market transactions (auctions and trades), the elements of commercial value that may be estimated, and the relationship between modelled commercial value estimates and prices actually observed from markets. In simple terms commercial value is driven by the net benefits (discounted net revenue) that spectrum use may provide. Where non-monetary benefits arise from spectrum use for public sector users, these can be monetised in payments made in the commercial market, and reflected in decisions to release spectrum from the public sector to the commercial market. Our approach does not focus on such non-monetary sources of spectrum value.

Gains in net commercial revenues from using a particular block of spectrum may arise from cost savings compared with alternative ways of meeting a business need and/or by opportunities provided to earn additional revenues. Revenues and costs are driven by engineering and commercial considerations, and both these aspects inform our analysis.

In Section 2 we consider a range of measures of commercial value and how they might relate to each other. We discuss possible ceilings and floors on value, as well as market clearing prices and their dependency on the particular circumstances being considered.

We consider whether commercial spectrum value curves could be constructed in a service neutral manner in Section 3, but conclude that the many dependencies between service and the drivers of revenues and costs means that there is little merit in attempting to find a general representation of spectrum value. Rather we suggest that for commercial applications there are several generic network types to be addressed.

Sections 4 to 7 deal with the commercial valuation of bands for cellular mobile, fixed links, single site systems and broadcasting networks respectively. Our conclusions are given in Section 8.

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[12] http://www.spectrumaudit.org.uk/pdf/20051118%20Final%20Formatted%20v9.pdf

[13] Pages 28-29, Recommendation 3.2, Independent of Spectrum Holdings, December 2005 op. cit.

2 Economics of Spectrum Valuation

In this section we first discuss the elements of value to commercial buyers and sellers of spectrum and which of these elements it may be practical to model. We then go on to consider the relationship between the opportunity cost of spectrum to commercial traders and traded prices, and how this is affected by market circumstances. Finally we compare values that may be obtained from auctions and trades. The reason for doing this is to determine under what circumstances auction prices may provide useful information for trades and to indicate the types of calculations we might undertake to derive estimates of commercial spectrum value relevant for trading.

2.1 Elements of commercial value

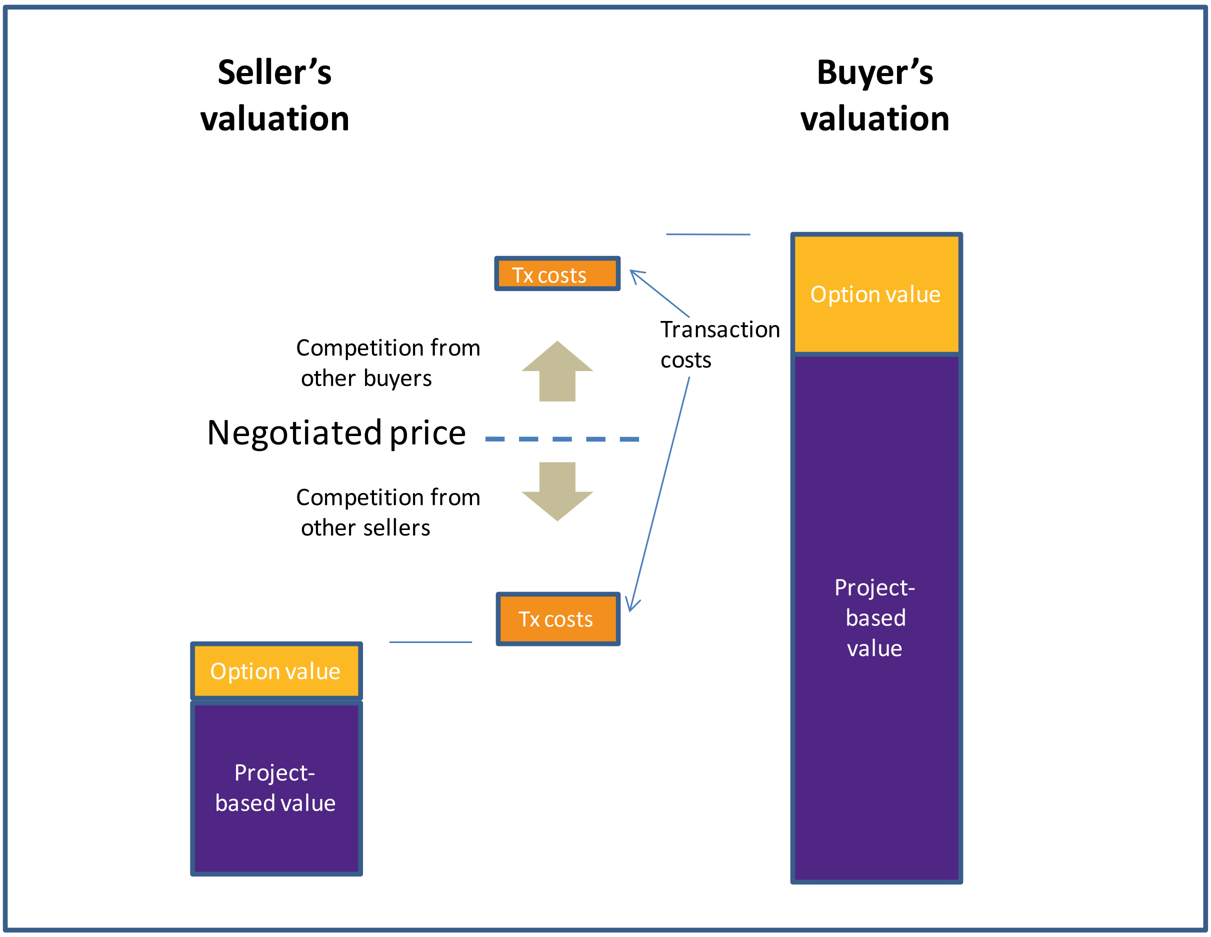
A rational firm can be expected to value access to spectrum based on the expected net present value (NPV) of future returns[14] where these are calculated valuing all other inputs (including capital) at their market price plus the option value from the flexibility offered by spectrum access.[15] The expected net present value of returns – what we call the project value – will comprise the returns from using the spectrum and the defensive value of the spectrum which derives from the desire to protect profits by limiting competition or raising competitors' costs. These elements of value are described below. The option value does not require the spectrum to be used. It is the value of flexibility offered by having the option in future to use the resource or trade it should the value to others be higher than the value to the user.

Assuming a trade occurs then the seller's valuation must be below that of a buyer. In this circumstance, a lower bound on the traded price is set by the seller's loss of value in forgoing its current activity plus its transaction costs. The upper bound will be set by the buyer's valuation minus its transaction costs. In a bi-lateral negotiation the final clearing price should lie between the two bounds. Figure 2-1 illustrates the bounds on clearing prices for the particular case where trade may take place. Note that no particular meaning should be attached to the relative sizes of the different elements shown in Figure 2-1.

[14]That is the discounted cash flows in a commercial context or discounted net benefits in a non-commercial context where the discount rate is the "normal" rate of return. This is the value from use of the spectrum or from trading the spectrum. In the long term the value of trades will be determined in part by returns from spectrum use.

[15] Note this analysis does not take account of agency problems between managers and shareholders. If spectrum access is necessary for the continued existence of the business then managers may be willing to pay more than the spectrum is worth to the shareholders in order to preserve their jobs.

Figure 2-1: Structure of the clearing price for spectrum



2.1.1 Project value

Spectrum may be acquired either to enhance an existing service or to start a new service.

In the case of service enhancement, the project based value of the spectrum will depend on the extent to which it allows the licensee to earn additional net returns (i.e. profits) or in a competitive market to maintain profits. Such profits may arise from:

- **Additional revenues**: For an existing service additional revenues may arise from being able to support increased demand or provide higher service quality.
- **Cost savings**: The total costs of providing a given service may be reduced if spectrum rather than some other input (e.g. infrastructure, another service) is used.

Where spectrum is fundamental to a service offered to end users (such as mobile telephony) it could be used to generate additional revenue and/or cost savings. When spectrum is used to support an internal business application (such as private business radio or fixed links) then it is used simply to reduce operating costs (assuming substitute technologies offer the same or similar functionality).

Alternatively a new service may be launched with the spectrum and this may offer the opportunity to earn above normal returns. Only if above normal returns are expected to be made is the project worth undertaking[16] and the scale of these above normal returns sets an upper bound on the spectrum value.

In practice the project valuation may include defensive valuations that are concerned with acquiring spectrum to protect market share and so profits in the same or other related markets. This is normal competitive behaviour but in some circumstances may lead to a significant lessening of competition. However, the application of competition law and/or explicit regulatory controls on spectrum holdings should in principle mean that anti-competitive effects are small and/or transitory.

Project value is more easily measured than option value, and so tends to be the focus of approaches used to measure spectrum value. The project value is measured by the expected NPV of future cash flows resulting from the use of the spectrum resource or from trading it, but in the long term, value will be a function of cash flows from use.

2.1.2 Option value

The value of spectrum could greatly exceed the expected value of spectrum calculated as the NPV of future cash flows if there is uncertainty over future applications and their value and there are sunk (or irreversible) costs associated with making investments.[17] The reason for this is that access to spectrum creates the opportunity, but not the obligation, to invest in the network and other infrastructure required to provide a wireless service at the time when expected returns are highest. This option value will be enhanced if spectrum rights are flexibly defined (e.g. there are minimal or no restrictions on the technology used, the type of service offered or the duration of rights[18]) so the rights holder can readily take actions to maximise returns in response to new information and opportunities.

The existence of option value means the spectrum has commercial value even if it is unused, because of the flexibility it gives the owner to respond to changing circumstances and to invest at the optimal time. The existence of option value may imply a positive overall price for an asset even when supply exceeds demand. In New Zealand positive auction values have been observed for cellular spectrum in circumstances where supply clearly exceeds demand.[19]

If there was a well functioning spectrum market then it might be argued that option values would be lower than otherwise, because users could acquire the spectrum they needed at the time it was optimal to invest. However, if all firms in the sector required additional spectrum at the same time (say because of rapid economic growth) then prices may be high and/or there may not be willing sellers. In addition, there will be transaction costs and delays associated with acquiring the spectrum through bi-lateral trading. Efficient trades may fail to occur if buyers and sellers base their respective valuations on different information (i.e. there is asymmetry of information)[20] or if trading requires revelation by the

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[16] Otherwise the money could as well be invested in other activities offering an expectation of above normal returns.

[17] Sunk costs might include costs of marketing a service or infrastructure costs that may have to be written off if a service fails e.g. because the second hand market in infrastructure works imperfectly or because equipment costs are falling.

[18] Note this assumes that spectrum rights do not include binding coverage/service roll-out obligations.

[19] Renewal of Spectrum Rights for Cellular Services Pricing Methodology, Discussion paper, July 2006, PriceWaterhouseCoopers and NZIER, Ministry for Economic Development, http://www.med.govt.nz/templates/MultipageDocumentTOC____20766.aspx

[20] There is an economics literature that discusses circumstances in which asymmetric information may cause markets to perform badly (when problems of adverse selection or moral hazard can occur) and potential mechanisms for addressing the

buyer of its spectrum use plans (e.g. so that the seller is assured that it will not suffer an increased risk of harmful interference). Option values will however be lower when 1) the duration of the spectrum right is reduced, 2) the use of spectrum is constrained, and 3) when there are use it or lose it conditions because all of these aspects reduce the benefits of flexibility that having the option to use the spectrum offers. [21]

A real life example of the potentially large size of option values is given by the case of undeveloped oil fields which may have a negative value if costs of production are compared with expected revenues given current oil prices (which equal expected future oil prices since oil prices, to a first approximation, follow a random walk). Nevertheless undeveloped oil fields do trade for values that significantly exceed expected value which may be negative. The reason for this is that the oil price may go up or down, and one would only invest in developing the field if the price went up. The option value of the undeveloped oil field is therefore positive. To provide a feel for the possible magnitude of the impact, we summarise the example presented by Dixit and Pindyck (2004) in Box 2.1.[22]

Box 2.1: Potential impact of real options on value of a resource

Consider an undeveloped oil reserve which, if developed, is expected to yield 100 million barrels of oil, and has a ten-year relinquishment requirement. If the value of the developed reserve is $12 per barrel (rather low relative to 2008 prices – an indication of how much oil prices vary), the present value of developed oil is $10.64 per barrel and the present value of development costs is $11.79 per barrel, then the expected net present value is -$115 million. One would not therefore expect the reserve to trade for a positive value based on static analysis.

However, the undeveloped reserve also has an associated option value since the price of oil may go up or down in future, and development can proceed conditional on reaching a threshold future oil price, or not proceed if the threshold is not reached. Assuming a standard deviation of oil prices of 0.142 the option value per dollar of development cost is 0.05245 and total development cost is $1,179 million. Hence the total value of the undeveloped reserve is $61.8 million, even though it could not profitably be developed given current oil prices. The key point is that this value is not based on an expectation that prices will rise, but the possibility that they may go up or down.

An example of the application of option values in relation to investment decisions involving wireless technology choices is provided in Harmantiz et al (2006).[23] In one example, consideration of option values roughly doubles the value of the project. Quotient and Indepen (2007) consider the value of the option to delay in relation to the allocation of licence exempt spectrum for fixed wireless access. In this case the value of the option to delay is modest relative to the expected NPV.[24]

Calculating option values is difficult because information on the uncertainty faced by firms may be very limited, and the option value depends on complex considerations including the nature of the underlying uncertainty (is it a random walk or mean reverting?), what the uncertainty applies to (output prices, input costs or technology?) and the regulatory-political environment (to what extent can investors exercise different options?). For these reasons we have not attempted to calculate

situation (through signalling and screening) remedies to this situation. See for example “Market for lemons: quality uncertainty and the market mechanism”, G Akerlof, Quarterly Journal of Economics, 1970, 84

[21] Trigeorgis. 2007. “Real options: managerial flexibility and strategy in resource allocation.” MITPress. Page 253.

[22] Dixit and Pindyck. 2004. Investment under uncertainty. Page 403.

[23] Five cases are examined: investment in 3G wireless; investment in integrated mobile and WiFi access; migration to wireless broadband internet services; valuing deployment of WiFi networks in enterprise markets; and valuing hosted VOIP services for enterprise markets. Harmantiz, Trigeorges and Tanguturi. September 2006. “Flexible investment deciisons in the telecommunications industry: case applications using real options.” Page 45. http://www.netinst.org/Harmantzis-Trigeorgis.pdf

[24] Quotient and Indepen. September 2007. “Higher frequencies for licence exempt applications.” Page 68. http://www.ofcom.org.uk/research/technology/research/exempt/higher/final.pdf

commercial option values. However, it should be recognised that when users trade or buy spectrum at auction they will in practice include option values in their spectrum valuations. Accordingly the illustrative results from our modelling may not be representative of actual commercial spectrum values in specific market situations.

2.1.3 Transaction costs

Transaction costs are one-off costs at the point of sale and will be incurred by buyers and sellers.[25] Both buyers and sellers will incur the costs of management time and legal support for negotiating a sale. It is also well known that firms review opportunities for change periodically not continuously because of the limited availability of management time to make strategic decisions (leading to selective intervention) and because of the scale of transaction costs.

Sellers (and possibly buyers) will also incur costs associated with vacating the spectrum they sell if it is currently used and/or with the potential loss of option value if the spectrum is not used. The costs incurred by the seller associated with vacating spectrum and potentially moving to another band or another service could comprise one or more of:

- Penalties for breaking contracts associated with the existing services (e.g. site rental contracts).
- Write-off of the accounting cost of existing equipment if there is no second hand market.
- The costs of removing existing equipment and installing new equipment.
- The risk or actuality of revenue loss in the transition to the new arrangements.
- The costs of operating duplicate systems so as to maintain business continuity. This may be particularly acute for services with many end users and/or where the applications in question are safety critical.

The nature and scale of these costs will depend on the situation being considered and the risks faced by organisations when changing their spectrum use. However we note that these costs are often mentioned by incumbents when asked by the regulator to change their spectrum use and may in some circumstances explain low trading volumes by commercial organisations.

2.1.4 Summary

In summary:

- Defensive values should not generally be included in the valuation approach because they derive from the exploitation of market power which is difficult to predict in a generic modelling framework.
- Option values are either zero or positive, and if positive they can be significant. However they are difficult to calculate in a generic framework and so are not included in our models. This means any values we derive are (subject to other uncertainties over input assumptions and value drivers) a lower bound on value.

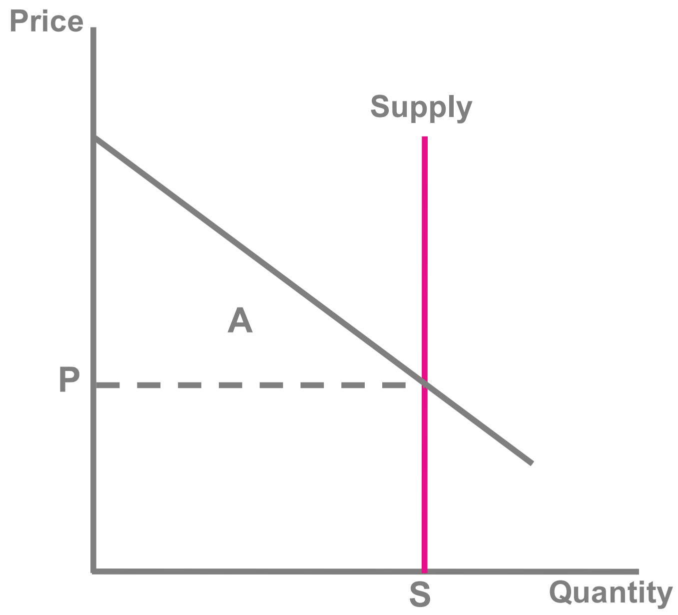
[25] Because such costs are typically sunk (i.e. irreversible) and trading decisions can be delayed there could be value in delaying this expenditure and making buy/sell decisions at a later date based on new information. This value is the option value of the money spent to cover transaction costs. For simplicity we ignore this complication.

- The focus of our valuation work is on the NPV of future cash flows for a commercial buyer. However, observed auction and traded values could include option and defensive values and this should be recognised when comparisons are made with calculated values.
- Transaction costs will need to be taken into account in considering the value of spectrum to buyers and sellers in a trading situation and/or when valuing spectrum by an incumbent use.

2.2 Opportunity cost and traded prices

Figure 2-2 shows a demand curve for a given block of spectrum of size S. Points on the demand curve give the willingness to pay of users in order of decreasing value as we move from to the right on the horizontal axis. In a well functioning market P is the market price and equals the marginal opportunity cost of spectrum. The area A is the surplus that accrues to spectrum users at the market clearing price P and is not relevant for the purposes of informing prices that might be delivered by a market (auction or trades).

Figure 2-2: Spectrum supply and demand



Now suppose all the spectrum S is assigned and a spectrum buyer with a willingness to pay PB appears (see Figure 2-3). What price might the buyer expect to pay? If the market was efficient and sellers did not incur any costs in undertaking the transaction then the buyer would be able to find the user (i.e. a potential seller) with willingness to pay P and would buy spectrum at this market clearing price.

Figure 2-3: Price for a spectrum trade

However, lack of suitable information may mean that the buyer does not find the user with the lowest willingness to pay and/or bargaining between the buyer and seller could result in a traded price that lies between P and PB.

By contrast auctions can theoretically deliver more efficient outcomes. In particular, an efficient auction (i.e. a second price auction) in which there are two bidders with equal access to relevant information determining spectrum value can result in an efficient allocation of the resource (assuming no collusion) whereas bi-lateral negotiation in which the buyer and seller do not know the other's valuation may not result in an efficient outcome.[26] An efficient auction should result in a price that is the willingness to pay of the second highest (losing) bidder (i.e. P in Figure 2-3) while bilateral trades, if they occur, could be at a price intermediate between the buyer's and seller's valuation. This will happen if the buyer does not know the seller's reserve price.

2.2.1 Impact of transaction costs

As discussed above sellers could incur significant costs in moving from their existing spectrum holdings – much more than simply the legal and other administrative costs of negotiating the trade. These costs push out the spectrum demand curve of sellers for the frequency band they currently occupy. This situation is shown by the darker (purple) demand line in Figure 2-4. The market clearing price rises to PS, and the traded price will sit above this price (i.e. between PS and PB).

[26] "Efficient Mechanisms for Bilateral Trading", Myerson and Satterthwaite, Journal of Economic Theory, v 29, 1983.

Figure 2-4: Prices when sellers' transaction costs are significant

Price

Supply

PB

Buyer willingness to pay

Range for
actual price

PS

P

S

Quantity

To take account of the possibility that the price at which incumbent users are willing to sell is different from the price at which they (and others) are willing to buy vacant spectrum it would be necessary to include transaction costs in the set of value drivers. This would allow us to derive values that better inform trades and values that will give some existing users incentives to vacate spectrum in a situation where the current assignment of spectrum is non-optimal.[27] .

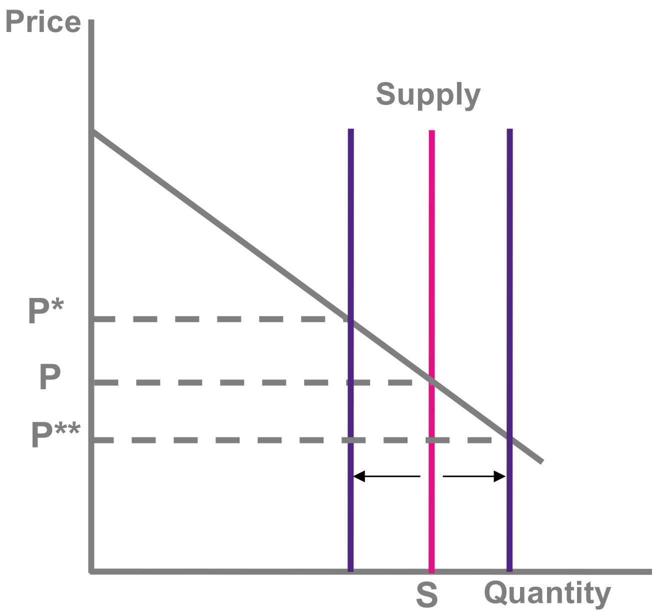
2.2.2 Amount of spectrum and price

The estimated commercial value of spectrum will also depend on the unit of spectrum that is being valued. Marginal changes in spectrum quantity will not greatly affect values. Trades and auctions may involve large (i.e. non-marginal) blocks of spectrum shown in a stylised way by the vertical purple lines in Figure 2-5.

Firstly, taking a static view in which the demand curve is unaffected by changes in the blocks of spectrum made available, removal of a block of spectrum will raise the opportunity cost of spectrum from P to P*, while adding a large block would reduce the opportunity cost from P to P**.

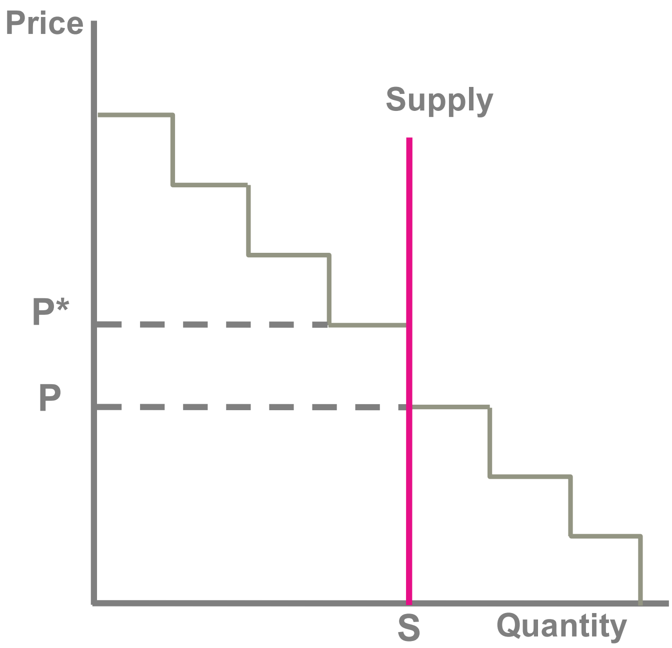
[27] This is often the case because historically assignments were not guided by price e.g. were made on a first come first served basis or as a result of a beauty contest. .

Figure 2-5: Prices with large changes in spectrum supply and demand unchanged



In circumstances where only large blocks of spectrum are of value to a user (e.g. if channels have a minimum bandwidth of 5MHz rather than say 12.5kHz) it is more appropriate to show the demand curve as having discontinuities at these block sizes. This is shown in Figure 2-6 with a stepped demand curve and incremental blocks being worth declining amounts. It is clear from this diagram that there is a range for the potential market clearing price between P and P*.

Figure 2-6: Prices with discontinuities in demand



2.2.3 Implications

If the demand curve varies continuously with price then the value of a small increment of spectrum should be similar to the value of a small decrement (as is assumed in Figure 2-2 above). However, there are reasons why in practice the demand curve may not be continuous:

- Adjacent bands may not be close substitutes and even alternative bands available for a particular service may not be close substitutes, for example, because of differences in the costs of using the bands.
- Users may require large blocks of spectrum to provide a service in which case small changes up and down in spectrum supply make little or no difference to prices.
- Users' willingness to pay for retaining a MHz of the spectrum they currently occupy is likely to exceed their willingness to pay for a MHz of additional vacant spectrum, assuming all else is equal. This is because the user is likely to incur transaction costs in moving out of the spectrum they currently occupy but no such costs are incurred when using vacant spectrum. Hence a discontinuity in value could occur between occupied and vacant bands outwith engineering or market related drivers of spectrum value.

If these situations apply then estimated values based on an assumption that a user has an increase in its spectrum holding could be considerably less than those based on assumed decreases in spectrum holdings. This means that when modelling spectrum value and/or interpreting values revealed by market transactions we need to think carefully about the specific scenario we are considering.

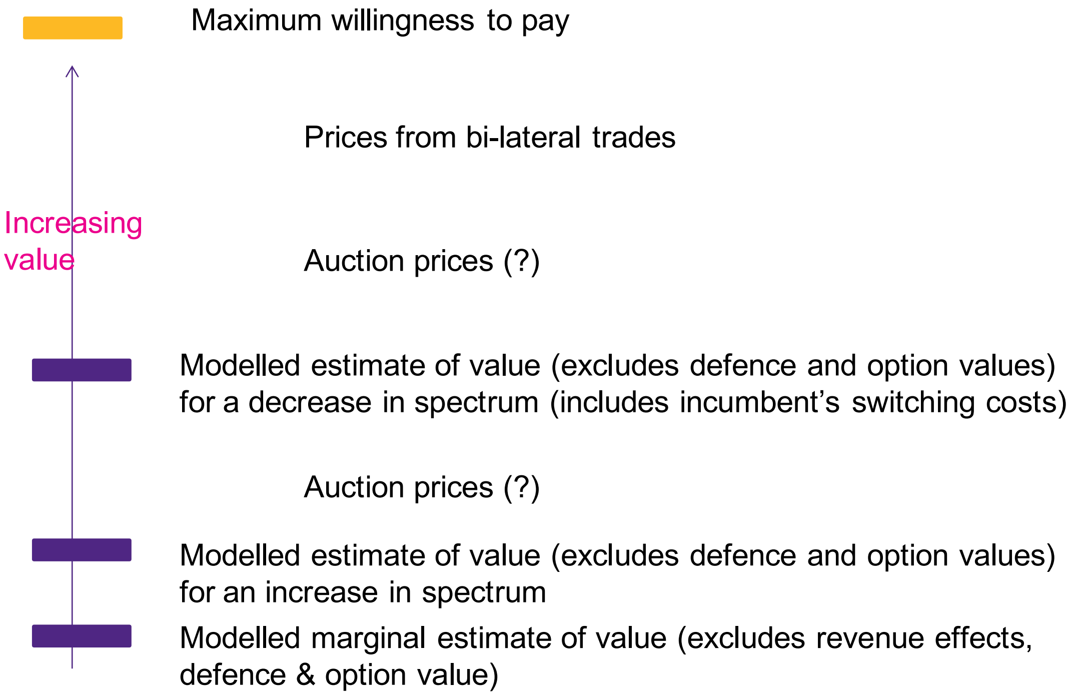
Finally we note that traded values are likely to exceed auction prices (all else being equal) because of transaction costs and information asymmetries between buyers and sellers. In practice comparable auctions and trades occur relatively infrequently so that all else is seldom equal, and the relative importance of this effect is accordingly difficult to assess from available evidence.

2.3 Different measures of value

The analysis given above suggests a range of commercial values could be estimated or observed for a given frequency range depending on the extent and nature of current use of the band. In Figure 2-7 we have sought to order different measures of value for a frequency range.

The smallest values are associated with small changes in spectrum use as we assume the impact of the change in spectrum on service revenues is negligible. If the latter is not the case then higher values may be obtained. A unit of additional spectrum will in general have a lower value to a user than the loss of a unit, though there may be some circumstances where this is not the case e.g. when the additional spectrum stimulates provision of new services. If a user is deprived of part of its existing spectrum holding it may incur transaction costs further raising the value of spectrum. Auction prices appear twice in the figure because it is not clear *a priori* whether these are larger or smaller than the modelled estimate of commercial value in the case where transaction or switching costs are included in the calculation.

Figure 2-7: Different spectrum value measures for a given frequency range



This suggests that any benchmarking against market values or direct use of them to set other prices should be done with care. In the remainder of this Section we discuss the impact of variability in market prices and known biases in comparisons between our modelled estimates of commercial value and observable values.

2.3.1 Variability of market prices

Market determined prices reflect the expectations of market players regarding spectrum value at a point in time. These expectations are private information so market prices are therefore thought likely to give a more reliable indication of value in particular circumstances for the market participants involved than estimates of commercial value calculated by a third party (such as a market commentator or a regulator).

However, market prices for similar spectrum can themselves vary (up and down) sometimes rapidly over time as expectations change. A recent example of this is given by results of the sale of 700 MHz spectrum in the US between 2003 and 2008. Table 2-1 gives auction results from 2003[28], a trade in 2007 and auction results in 2008.

[28] There were also two auctions of lots that were unsold in the initial 2003 auction (no 44).

Table 2-1: Summary of US UHF spectrum auction results

Year	Licence	Population Covered	Amount Bid (total)	Per MHz per Pop	Comments on winning bidders
2003	1 x 6 MHz (Block D, lower band)	237M	$38.0M	$0.027	Qualcomm – Mobile TV. Still had incumbent TV services in some areas
2003	2 x 6 MHz (Block C, lower band)	179M	$29.0M	$0.014	Aloha – still had incumbent TV services in some areas
2007	2 x 6 MHz (Block C, lower band)	179M	$2.5 Bn	$1.16	Traded price between Aloha and AT&T
2008	2 x 6 MHz (Block A, lower band)	298M	$3.88 Bn	$1.09	Acquired by Verizon and various local / regional operators
2008	2 x 6 MHz (Block B, lower band)	298M	$9.07Bn	$2.54	Acquired by AT&T and various local / regional operators
2008	2 x 11 MHz (Block C, upper band)	298M	$4.75Bn	$0.72	Acquired by Verizon. Large regional area licences offered. Open access conditions– fewer bidders than blocks A and B where no open access mandated.
2008	2 x 5 MHz (Block D, upper band)	298M	$472M	$0.158	National licence, obligations to share with public safety services. Bid by Qualcomm – reserve not met
2008	1 x 5 MHz (Block E, lower band)	298M	$1.27Bn	$0.852	Acquired by Qualcomm and Frontier Wireless.

Source: FCC and Plum analysis

The first auction in 2003 involved spectrum that was still being used by TV broadcasters, but which had to be vacated by 2009 – successful bidders also had the option to negotiate earlier closure with the broadcasters. At that time there was no readily available equipment for two-way mobile communications in the band and mobile TV technology was in its infancy. By 2008 and the second auction, the bidders could be confident that TV services would have ceased operating by the time they planned to make use of the spectrum, a number of vendors had committed to the manufacture of 3G mobile equipment in the band, mobile TV services were commercially available and the band had been internationally harmonised for IMT services at WRC07. It is not surprising therefore that the spectrum value (per MHz per pop) increased significantly (by factors of up to 100 depending on the frequency range and restrictions on its use) between 2003 and 2007/8.

This evidence of significant variability in spectrum value, seemingly in response to medium-term changes in technology development, regulatory conditions and the market situation, means any model of spectrum value needs to be complemented by a database of current information on expectations about the key value drivers. These information demands are considerable. However, if this is not done, any calculated values will often appear to be wrong and/or in conflict with market values derived at the same time and in particular at different times.

2.3.2 Biases in opportunity cost estimates

The allocation of spectrum between broad classes of service has been derived historically through administrative processes conducted at a national and international level, and as a result is unlikely to be optimal from an economic perspective (because of the absence of price signals driving allocation decisions). Furthermore the "optimal" allocation is dynamic in the sense that it changes over time in response to technology and market developments and changes in social priorities (e.g. the balance between civil and military activity). This means that estimates of the marginal benefit of a given block of spectrum to different users/services could differ widely.

As discussed in Indepen and Aegis (2007)[29] opportunity cost can be estimated using judgement given a number of marginal benefit estimates for different services/users (at a disequilibrium) that could use the spectrum in question. Judgement is required over the level of uncertainty of the value estimate and relative slopes of competing demand curves in coming to a view over what, if any, adjustment is appropriate in the circumstances for which different spectrum valuations are required. For example Indepen and Aegis (2007) proposed a rule of thumb for deciding an adjustment to opportunity cost estimates when deriving an AIP – generally a downward adjustment of 0-40%.

2.3.3 Recovery of spectrum management costs

When comparing auction prices with other spectrum value estimates it is also necessary to take account of how spectrum management costs are recovered. For example, in principle spectrum users could pay two sets of fees to Ofcom – one set to recover its spectrum management costs (because users cause these costs in varying degrees depending on the nature of the managed spectrum concerned) and another to reflect some estimate of Its the spectrum's underlying value absent spectrum management costs. In practice, and in accordance with the current legal framework, this disaggregation of user fees does not occur – and may not occur in the environment of a commercial band manager hypothesised in this report.

Instead therefore the situation in practice for Ofcom managed spectrum in the UK is as follows:

- In bands with no relevant excess demand Ofcom charges licence fees that are intended to contribute to its spectrum management costs.
- In bands where excess demand is a relevant consideration AIP is instead applied, with no distinct fees for the spectrum management component of opportunity costs (as incurred by Ofcom). AIP is set conservatively rather than reflecting the expected commercial value of the spectrum.
- In auctioned bands the winning bidders pay the auction price (typically reflecting the second highest bids) but no additional licence fees are payable for the initial term (typically 15 years) of the licence. In most cases the on-going spectrum management costs then incurred by Ofcom (as opposed to the successful bidder) in relation to these licences seem likely to be small.

This means that when making comparisons between auction results and licence fees it is necessary, among other things, to consider whether bidders are likely to incur significant spectrum management costs of their own and whether this has been reflected in the terms on which spectrum is licensed to them. All other things being equal (which they seldom are) auction payments may appear low relative to AIP or licence fees because of bidders' additional spectrum management costs.

[29] "Aeronautical and maritime spectrum pricing", Indepen and Aegis, Ofcom 2007

2.4 Conclusions

A rational firm can be expected to value access to spectrum based on the expected net present value (NPV) of future returns where these are calculated valuing all other inputs (including capital) at their market price plus the option value from the flexibility offered by spectrum access. The expected net present value of returns will comprise the returns from using the spectrum – what we call the project value. Trades will also be affected by the scale of transaction costs faced by buyers and sellers. In many cases these will be include the costs of ensuring communications can be maintained in the transition to a new frequency band or service. Transaction costs associated with moving frequency band could be a significant determinant of commercial spectrum value for some users in congested bands.

Option values are either zero or positive, and if positive they can be significant. However they are difficult to calculate and so are not included in our models. This means values we derive could represent a lower bound on value, depending on the confidence which can be attached to other input drivers of value in the modelling. The focus of valuation work will be on the NPV of future cash flows. However, observed auction and traded values will include the option value as well as the project value of spectrum and this should be recognised when comparisons are made.

There are a number of circumstances in which estimated values for an increment in a user's spectrum holding will be less (and possibly significantly less) than those based on decrements. These include situations where

- Adjacent bands may not be close substitutes and even alternative bands available for a particular service may not be close substitutes, for example because of differences in costs of using the bands
- Users may require large blocks of spectrum to provide a service efficiently in which case small changes up and down in spectrum supply have make little or no difference to prices.
- Users' willingness to pay for the spectrum they currently occupy exceeds that for additional vacant spectrum because of transaction costs.

These situations seem likely to occur in practice and so when modelling spectrum commercial value and/or interpreting values revealed by market transactions it is necessary to consider whether the values relate to increments or decrements in spectrum holdings and the size of users' initial spectrum holdings.

Evidence of variability in spectrum value, say in response to changes in technology, regulatory conditions and the market situation, means any model of spectrum value needs to be complemented by a database of current information on expectations about the key value drivers. These information demands are considerable. However, if this is not done, any calculated values will often appear to be wrong and/or in conflict with historic or current market values.

3 Modelling project based value

To meet the study objectives of providing insight into the major drivers of commercial spectrum value and developing models of generic value, we address the following questions

- Can we construct a service neutral model of spectrum value?
- If not, is it then possible to derive a discrete set of representative values for the set of services able to use a particular block of spectrum?
- What generic models can we produce to estimate representative values?

A useful representative value is one about which there is low variability given the specific characteristics of the organisations that may use the spectrum.

3.1 A service neutral approach?

Can we usefully construct a model of spectrum value that is independent of the service provided? Spectrum value derives from the cost savings from using radio and/or the ability to generate additional service revenues (from a new or existing service). Cost savings depend on the nature of the radio infrastructure, the spectrum/infrastructure trade-off and the availability of substitute non-radio based communications technologies. These drivers of value typically vary by service.

In particular:

- There is no generic network/receiver configuration that can be used to characterise all services. For many system types, networks and spectrum usage are planned in the same way with equivalent network entities and functions, but the technical parameters and costs vary according to the specific needs of the service being offered. This means that the cost advantages of using different frequency bands vary by service/application, and hence the value of spectrum varies by service and application.
- The end-user requirement depends importantly on the service i.e. some requirements can only be met by particular services and not others (e.g. fixed versus mobile). This also affects the nature of receivers (e.g. size, shape and portability) that can be used which varies by frequency because of physics/engineering constraints. Hence some user requirements cannot be met at particular frequencies.
- User willingness to pay for the service is also partly determined by the availability of substitute applications and platforms. For example, fixed services have more close substitutes than mobile services and so (all else being equal) we would expect the latter service to have a higher value of spectrum than the former.
- Some services are more tolerant of geographic and/or frequency adjacency than others (e.g. PBR versus cellular geographically) and hence the nature of adjacent services affects each others' value to different extents by service and by frequency. This issue will be of increasing importance with co-primary designations internationally and release of shared spectrum. All such factors have been ignored in the modelling for this report.

One could average values across all potential applications, weighted by relative probability, and in that way seek to obtain a representative average market value. Plotting this value across a range of frequencies would probably result in a smoother function than a plot of service specific values.

However, in the foreseeable future international constraints, trading and use restrictions, and legacy global investment in equipment and international frequency harmonisation will persist implying a large number of value breaks across frequency even if long term probabilities are factored in. Hence we do not believe that this would be useful in providing insight into generic spectrum value or in informing spectrum markets on the potential value of trades. Rather such an approach would simply reflect the assumptions used to derive the average from a wide range of potential applications, services and specific spectrum users.

We conclude that it is not useful to try and derive a generic spectrum value function because of the strong dependency on the service provided. At a minimum service specific valuation functions should be considered.

3.2 Deriving a representative spectrum value for each service

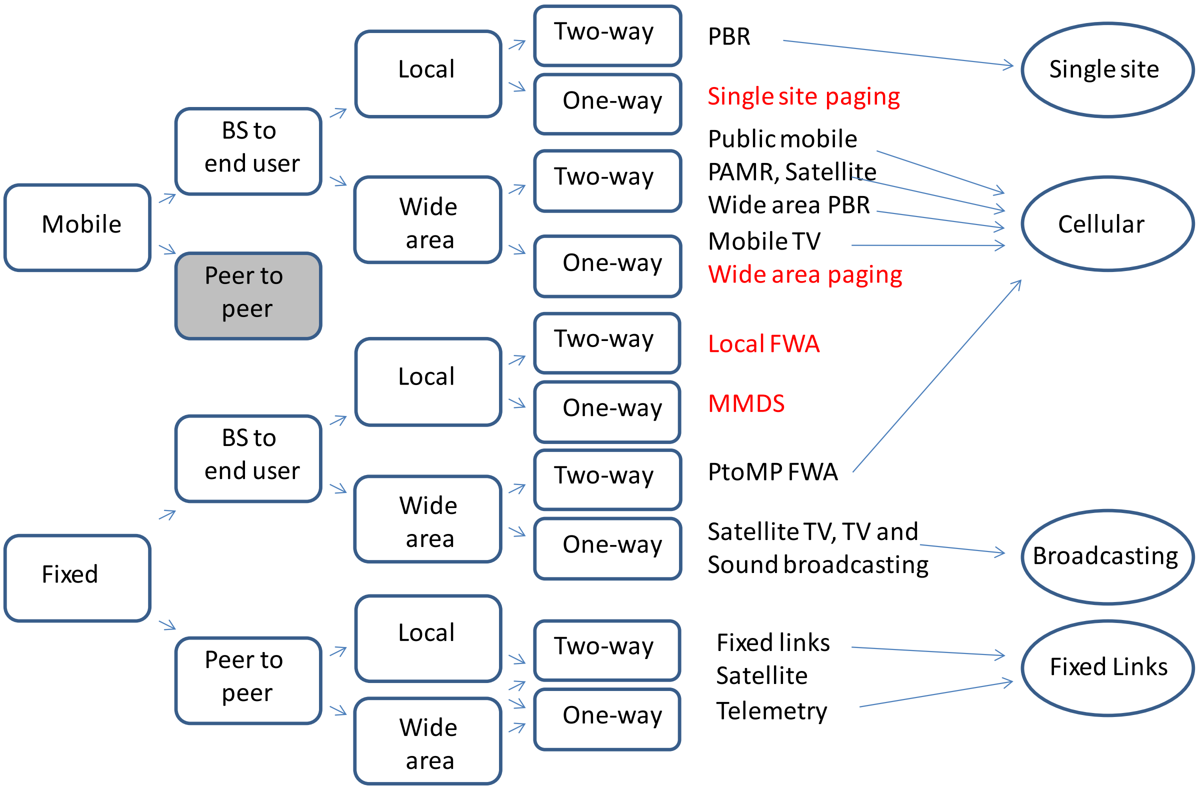
Before a representative value can be estimated for a particular service we need to consider how to model project based value where multiple users with broadly the same transmitter and network types share the same spectrum frequencies. To realise the full potential commercial value of spectrum for this type of service may require a joint decision by multiple users of the spectrum or coordination between multiple purchasers. To overcome these difficulties we consider spectrum value from the point of view of a hypothetical commercial intermediary (band manager) who would coordinate deployment by users and aggregate their willingness to pay. A central tenet of such modelling is that spectrum only has standalone value in a specific geographic region where there is excess demand. If equivalent spectrum is available from another source (e.g. Ofcom or another band manager) at modest cost then this alternative places a cap on the willingness to pay of the band manager's customers.

A rigorous approach to valuation requires consideration of the full range of applications that currently use spectrum and potential uses in the future. Models are usually structured around the deployment of fixed infrastructure (except in the case of simple peer to peer mobile applications). To simplify the assessment of network costs, it is useful to categorise the approach to network planning based on distinct characteristics namely:

- Fixed or mobile.
- Base station to end user or peer to peer communications.
- Local or wide area deployment by a single user organisation.
- Two way or one way communications.

Some permutations are not meaningful in a trading context. For example, mobile peer to peer use is achieved through licence exempt use not involving the purchase of spectrum. Similarly, local and wide area, and one way and two way fixed links are each planned in the same manner. The permutations of these characteristics are shown below in Figure 3-1 together with example applications. The examples in red are in decline and so are not considered further. As can be seen we have grouped the applications by the type of network required – this gives a total of four reference networks.

Figure 3-1: Applications and reference networks



In this report we have focussed on communications services and broadcasting. We do not consider low powered applications, scientific services or radio navigation and radio location services. The remaining services and applications are the ones for which significant value is likely to arise in a practical trading context.

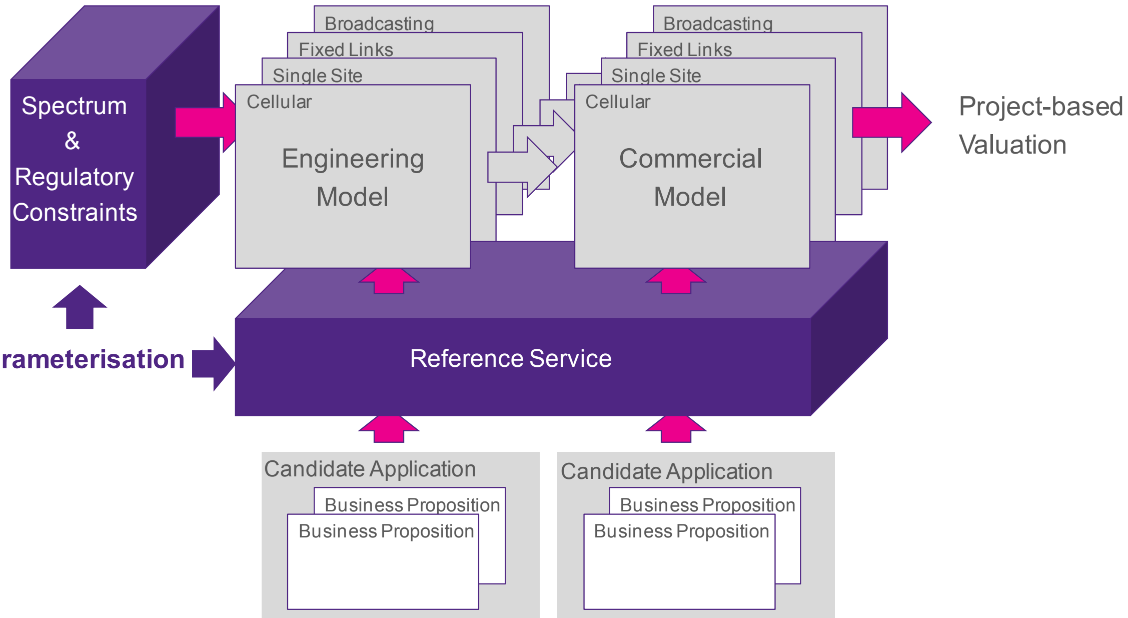
For modelling purposes we can consider the four categories of network structured around their methods of frequency planning and deployment.

- Cellular networks – where fixed infrastructure provides communications to multiple fixed or mobile end-user terminals. One to one communication over a wide area with intensive frequency re-use is achieved by deployment of small cells and seamless inter-cell handover. Coverage is usually contiguous within regions, and frequency use is carefully planned to maximise capacity whilst keeping interference within acceptable limits. Costs are capacity and coverage driven. Revenue is mainly driven by the number of subscribers/users.
- Single site deployments – fixed infrastructure provides communications to multiple mobile end-user terminals. Coverage is localised and may be sporadic towards the edge of the target coverage area. Frequency use is planned by the regulatory authority or a band manager. Large geographic separation between co-channel base stations is required, limiting re-use and the number of users that can be served. These systems are low cost (coverage and capacity driven), but have low revenue potential.
- Fixed point to point networks - One to one communication between two points, use of high performance directional antennas allowing intensive frequency re-use, though capacity is limited along specific routes. These are cost effective for provision of backhaul and for access to large users.

- Wide area broadcasting networks – One to many communication that typically serves a wide area from a single site. Frequency re-use may be limited due to interference considerations, though digital technology can enable multiple sites to use a single frequency within a contiguous geographic area. Costs are essentially coverage driven, however the need for user aerials to be oriented towards the transmitter limits the extent to which user organisations are able to vary network deployment. Revenue is driven by audience/number of subscribers.

At a conceptual level the model structure we had in mind for each of the four reference services is as shown in Figure 3-2. In practice for those services for which we have produced estimates, the engineering and commercial models were amalgamated into a single model structure.

Figure 3-2: Overall model structure



3.3 Treatment of existing licence fees

For those licensees that have acquired spectrum through auction, licence fees are not paid and so do not need to be considered when deriving a commercial value for the spectrum for trading purposes. However, licence fees or AIP are paid by licensees that have not acquired spectrum through auction and we need to consider whether to value the spectrum taking account of these payments or not. We have chosen to value the spectrum excluding these payments for the following reasons:

- The estimates are then more directly comparable with auction results (as auctioned spectrum is not subject to these fees).
- When considering a trade of spectrum which is subject to licence fees/AIP the traded value can be derived by simply netting off the licence fee/AIP payment.
- The level of fees/AIP can vary depending on the detailed circumstances of the user (location and technical characteristics of transmissions) and we have sought to abstract from this level of detail.

However, licence fees/AIP may affect the demand for the spectrum. We have used current licensing data for fixed links and PBR to derive value estimates and the impact of licence fees/AIP on current levels of demand (as revealed by licensing data) has not been taken into account in our analysis. This would require estimates of the price elasticity of demand for spectrum for these services and we are not aware of any such estimates. If demand is likely to be higher in the absence of licence fees/AIP then our value estimates are likely to be biased downwards.

3.4 Summary

In this section we suggest that:

- It is not practical to construct a service neutral model of spectrum value because much of the value of spectrum is a function of network structures and final communications markets, both of which are service specific.
- Most commercial services deriving relatively high commercial value from spectrum use can be characterised as one of four network types – cellular, fixed point to point, single site and broadcast networks.

We therefore consider how commercial spectrum value might be derived for these four cases in the remainder of this report.

4 Cellular Mobile

When estimating the project value of spectrum for cellular mobile networks, value can arise from:

- Cost reduction in the provision of existing or already planned services in highly congested areas through use of additional spectrum for capacity enhancement and/or superior in-building coverage or the use of lower frequencies in rural areas to improve geographical coverage.
- The launch of new services not supportable practically within existing spectrum allocations. These services could include consumer broadband and mobile TV and may be launched by existing mobile network operators (MNOs) or new entrants.

The project value of a specific block of spectrum will be the sum of these two valuations. In each case the project value of additional spectrum to a purchaser is the difference between the NPV of its overall cash flows with and without the additional spectrum.

4.1 Value drivers

The frequency of the spectrum being valued is a major driver of value in that above about 3 GHz it is increasingly difficult to achieve reliable non line of sight operation and below approximately 300 MHz the cellular approach to network design becomes increasingly impractical, as the frequency re-use distances and RF component sizes become excessive.

Within the 300MHz-3GHz frequency range, the project value of spectrum to an operator is determined by the NPV of expected revenues less costs, therefore the primary value drivers are revenue and cost drivers. We discuss below how these affect the absolute and relative value of different frequency bands.

4.1.1 Revenue drivers

Revenues will depend on demand for the services offered and their price, which in turn are driven by economic variables such as income and competition from other (substitute) services and other operators (and their relative price and service quality). Price at any point in time will be largely determined by costs in reasonably competitive markets, though price differentiation that is not cost reflective may be used to recover fixed/common costs. In practice revenues are often modelled by assuming a forecast growth in ARPU, subscriber numbers and traffic with weak dependency between these variables because the income and demand elasticities are not well understood.[30]

Service attributes and so demand will depend in part on the extent of geographic service coverage nationally and international roaming possibilities. The latter will depend in part on the extent to which the equipment and frequency bands are harmonised across those countries users are most likely to visit.

These variables and their effects are listed in Table 4-1.

[30] For example the way in which the elasticities are likely to change in future as some service markets mature and new services are offered is not known.

Table 4-1: Summary of major revenue drivers

Revenue component	Drivers
ARPU	Income growth within target market segments Competition from other operators and services (e.g. fixed and WiFi) Range of services offered Coverage - Roaming capability (e.g. harmonisation) and national coverage Service quality – capacity, dropped calls, latency etc Investment in brand development
Subscribers	Population growth Logistic growth in penetration for market as a whole Market share for particular operator

The value of spectrum to a licensee is governed by expectations about the future values of these revenue drivers. While there could be common views across the market for the values and impact of factors such as income growth and population growth, and competition will lead to some similarity in service offerings and coverage, it is clear that some of the variables will be operator specific particularly the traffic and market share assumptions and commercial strategies.

The relative value of different bands is driven by users' coverage, roaming and service quality requirements. Harmonised bands offer the potential for inbound roaming (assuming services are deployed elsewhere in the world) whereas this is not likely with non-harmonised spectrum. If there was a fluid spectrum market we would expect to see the value of spectrum in a particular band start to rise as the likelihood of harmonisation increases. This is rarely seen in practice as spectrum often only enters the market for a particular application once it has been harmonised.[31]

Lower frequency bands offer greater coverage potential and higher bands generally offer wider bandwidth (and so better capacity and/or service capability) but these advantages can be offset in both cases by deploying more infrastructure. Hence even where the value of spectrum arises primarily from new service opportunities, its value will be also be driven by the size of network deployment costs (base station equipment, site costs, backhaul etc).

4.1.2 Cost drivers

Cellular mobile costs comprise infrastructure (or network costs), marketing costs (mainly handset distribution and subsidies) and administrative costs (e.g. billing). Administrative and non-handset related marketing costs will affect the overall level of prices and so service demand and viability. In this way they affect generic value of spectrum for a given service proposition but as they do not tend to vary with frequency, they do not affect the relative value of different frequency bands.

However, infrastructure and handset subsidy costs vary according to the frequency band under consideration. The main effects are as follows:

[31] Typically the regulator clears spectrum that is newly harmonised and then tenders licences. For example, this process is currently occurring in some countries in the upper part of the UHF band as it is refarmed from analogue TV to possible use by mobile applications.

- Frequency harmonisation and standardisation reduce infrastructure equipment and handset costs and so increase spectrum value.
- Lower frequency ranges offer better coverage including in-building penetration in urban areas and therefore allow fewer base stations to be deployed in areas where the network is coverage limited. Whilst as a general rule path loss falls with frequency (and hence the cost of coverage decreases), this benefit tends to be offset at frequencies below about 700 MHz by decreasing antenna efficiencies.
- Amount of spectrum – the more spectrum available the fewer base station sites that will be needed to support the capacity required, and hence results in lower operating costs. However, the benefit declines with increasing amounts of additional spectrum resulting in a lower value per MHz as the amount of additional spectrum increases.

The cost drivers are summarised in Table 4-2.

Table 4-2: Summary of major cost drivers

Cost element	Driver
Number of base stations/sites	Frequency range, amount of spectrum, mix of services, traffic levels, service quality and coverage
Back haul costs	No of base stations and price of backhaul
Base station equipment costs	Band harmonised or not
Hand set subsidies	Band harmonised or not

4.1.3 Complementarity of existing activities

Both revenue and cost drivers are affected by the existing assets held by an operator. Revenue assumptions depend on the market positioning and market share of the operator. Cost assumptions depend upon existing spectrum held by the operator and its historic investment in sites.

A more complete list of value drivers arising from existing activities is summarised in Table 4-3.

Table 4-3: Summary of drivers arising from existing activities

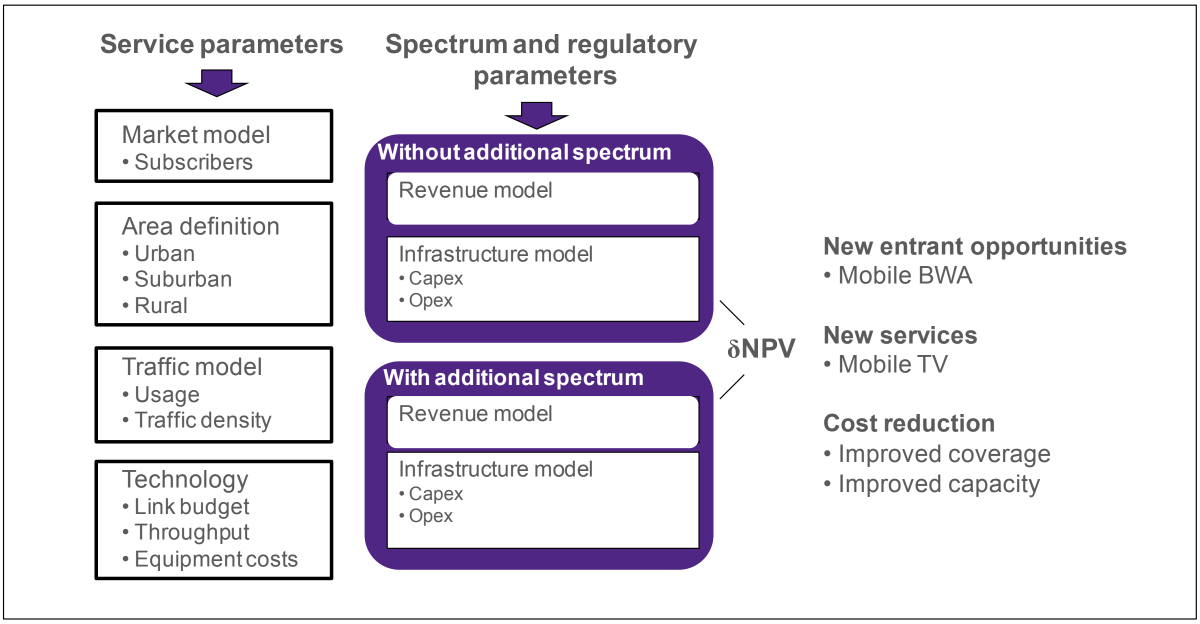
Revenue/Cost element	Driver
Number of base stations required for coverage	Lower frequencies than existing spectrum holdings may allow reduction in the number of sites (or fewer new sites going forward where network traffic is growing)
Number of base stations required for capacity	Additional frequencies will increase the capacity per site but the reduction in base stations for capacity depends on the quantity of spectrum applied per site in the existing network
Marketability of services enabled by the spectrum	Mix of existing services (degree to which new services are seen as complementary by the market) Penetration of key market segments (affects ability to cross-sell new services enabled) Degree of own versus MVNO subscribers

4.2 Model framework

Our approach to estimate spectrum value to cellular mobile operators started with the development of a comprehensive model to assess project-based mobile cellular business propositions. The model calculates the NPV of potential uses of the spectrum considering these revenue and cost drivers.

Revenues are determined from the underlying population and forecast for market penetration and Average Revenue per User (ARPU) for the services. Costs and revenues are considered both with and without the additional spectrum being available to the network operator. The majority of changes in cost base relate to capital expenditure on the Radio Access Network. However, there are also operational cost differences to be taken into account that are associated with maintaining the network and site rental. The high level structure of the evaluation model is shown in Figure 4-1.

Figure 4-1: Process for value estimation using the Cellular Reference Network



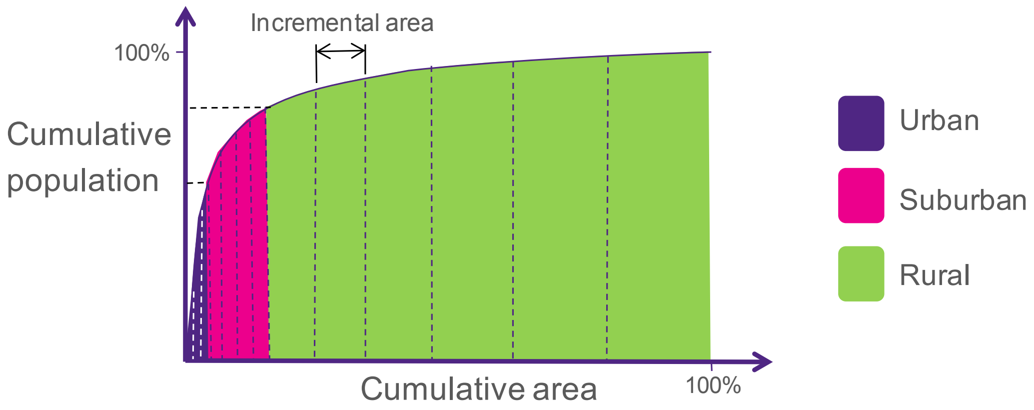
Not all business propositions using the additional spectrum will involve a change in revenues. Where the major source of value is derived from cost reduction, the total value of the spectrum will be determined by considering these costs both with and without the spectrum being considered. The Net Present Value (NPV) of the difference in costs represents the maximum value that might be attributed to the spectrum for that business proposition. Offsetting any cost reductions will be the degree to which the spectrum may lack harmonisation internationally (which would otherwise allow roaming revenues and economies of scale on equipment supply) and is harmonised with technology already deployed by the operator. Spectrum value calculated in this way is only valid where the amount of spectrum offered is sufficient for practical implementation and in channel configurations suited to mobile deployment.

Where the major source of value is derived from a new network deployment or it facilitates the introduction of new services, the potential revenues associated with the opportunity were included in the model. For these cases it is necessary to calculate the NPV of the business proposition as a whole.

In simulating commercial choices made by operators, the model needs to consider a new entrant opportunity at various levels of deployment ranging from national (i.e. the coverage typically provided by a GSM network), to a far more focussed and niche service offering based on serving highly populated areas only. This is because an operator would tend to maximise returns on investment by only rolling out services in areas which would add to the overall value of the spectrum.

The approach taken to this task was to establish the surplus profit that may be obtained from a service which is offered to a specific density of subscribers (based on service penetration rate assumptions). The value could then be integrated across the UK (or region for a regional assignment) by using a stratified breakdown of area according to population density as shown in Figure 4-2.

Figure 4-2: Stratified breakdown of UK area



By summing across each stratum that generates a positive NPV the maximum value of the spectrum can be found. In this way the model simulates the degree of rollout that maximises value.

The technical elements of the model define the essential physical characteristics of the network, including the link budget, bandwidth efficiency, frequency re-use factor, network configuration (antenna heights, number of sectors per base station), compatibility with other services and the frequency limits within which the service can be deployed. Definition of the user’s existing spectrum (where applicable) and the “new” spectrum which is the subject of the value estimation are important input parameters to the model. The model also includes unit cost estimates for key elements of the network infrastructure and for user terminals.

The model uses the input frequency parameters and the built-in network physical parameters to determine the infrastructure required to achieve a given level of population coverage. In the case of an existing operator this was determined both with and without the newly acquired spectrum, so that the impact of the additional spectrum on network costs could be estimated.

4.2.1 Model parameters

A summary of the main model parameters for the integrated engineering and commercial model is shown in Table 4-4.

Table 4-4: Main parameters for estimating the project value of offered spectrum

Market parameters	Cost parameters
Population and population growth	Offered spectrum (frequency range)
Forecast of terminal penetration	Existing assignment (frequency range)
Forecast of service penetration	Urban / suburban / rural cell coverage areas in km^2
Number of operators	Urban / suburban / rural cell mean throughputs in Mbps
Median market share	Frequency reuse characterisation
ARPU	Site establishment costs
ARPU annual growth	Site equipment costs
Busy hour voice traffic per user	Backhaul costs
Voice traffic annual growth	Core network costs
Busy hour data traffic per user	Annual reduction in equipment costs
Data traffic annual growth	Installation costs
Coverage requirement (% of population)	Network maintenance
Cost of capital (pre-tax real)	Site rental
	Marketing costs
	Admin costs
	Terminal costs (high volume)
	Cost of content

As is evident many of these parameters will depend upon the precise characteristics of the licensee. This means that the calculated value of spectrum will be dependent on assumptions about the average or marginal user. There are also some linkages between the revenue and cost variables (e.g. optimistic market assumptions would lead to more volume in production of handsets and network equipment and therefore greater annual reductions in equipment costs).

Confidence in the values applied to these parameters is essential to have confidence in the results. In general, there is less variability regarding the cost parameters than market parameters since they are more related to best practice within the mobile sector than individual operators' strategic choices.

4.2.2 Approach to estimation

The model described above is complex and requires a large number of assumptions. While some assumptions can be made with reasonable confidence (e.g. unit equipment costs) others are reliant on:

- The current assets and operations of the MNO (number of sites, subscribers and usage per subscriber). With few existing MNOs and considerable variability in market share and nature of their subscriber usage, it is difficult to derive a single set of typical assumptions that is representative of all current and potential future MNOs.
- Market forecasts for the mobile sector (ARPU growth and traffic growth). Forecasting mobile services is hugely uncertain and spectrum value depends upon the aspirations and market confidence of individual operators.
- Assumptions about the sources of new revenue streams, including service descriptions, service take-up and price. These are even more reliant on the specifics of the individual MNO's current assets, market presence and confidence in future mobile markets.

It is not possible to present meaningful typical or generic values making assumptions about all these factors and to do so could be misleading. Therefore we have used the cost reduction scenario alone for which we require assumptions concerning number of subscribers, traffic levels, numbers of sites and site costs, to illustrate the importance of different drivers in value. The results of this analysis are presented in the next section.

4.3 Results

The cost reduction scenario calculates the value of the cost savings accruing from the deployment of additional spectrum for a Mobile Network Operator with existing spectrum assets. The methodology relies heavily on the future traffic growth being able to be accommodated within the existing spectrum holdings (for a sensible "without additional spectrum" scenario). Another assumption underpinning this model is that reducing costs by using alternative spectrum in this way will not have a significant impact on the revenues. We consider this a reasonable assumption since prices are generally set by the costs of the marginal producer and are strongly influenced by branding and perceived service quality.

To illustrate the potential for value arising from cost reduction we considered a typical 3G rollout where an operator intends to increase the subscribers on its network over the next 10 years from a starting level of 5 million subscribers to 7.5 million, with linear growth for the transition between these two states.[32] Over this period we have assumed that the population coverage remains static at 90% of the UK population,[33] Overall traffic levels increase in line with the number of subscribers and per-user traffic levels.

The major drivers are summarised in Table 4-5. In reality, the drivers are variable according to the precise circumstances surrounding the MNO therefore we have assumed an illustrative range of

[32] The increase in market share is largely a function of marketing investment and it is assumed that additional revenues justify such investment in marketing.

[33] Although extending coverage further into rural areas could enable further cost reduction if the new frequencies are lower than the existing frequencies, this is genuine value only if additional revenues could justify such network expansion without the additional spectrum.

values for each parameter where they contribute to a low, medium and high valuation scenario. It is important to note that each scenario is intended to illustrate the spectrum value that might be perceived by a single hypothetical operator having these starting characteristics; in reality operators have a variety of market shares and existing spectrum holdings leading to an even wider range of valuations.

Table 4-5: Major parameters driving the cost reduction model

Parameter		Low scenario	Mid scenario	High scenario
Existing spectrum holding	Frequency	900 MHz	1750 MHz	2100 MHz
	Quantity	2 x 15 MHz	2 x 10 MHz	2 x 5 MHz
New spectrum	Amount	2 x 5 MHz	2 x 5 MHz	2 x 5 MHz
Subscribers	Current level	5 Million	5 Million	5 Million
	Level after 10 yrs	5 Million	7.5 Million	10 Million
In-building penetration loss	Additional loss for deeper coverage	0 dB	0 dB	+13 dB
Data usage in busy hour (per user)	Current level	0.5 kbit/s	0.5 kbit/s	0.5 kbit/s
	Level after 10 yrs	20 kbit/s	40 kbit/s	60 kbit/s

The cost reduction scenario valuation was assessed for additional 2 x 5 MHz of spectrum in the frequency range from 460 MHz to 3000 MHz. Using the mid scenario values as a baseline, four of the parameters facing the greatest uncertainty due to existing MNO circumstances or future market were varied to illustrate the range of project-based spectrum valuations that may occur.

The range in potential project-based value of additional non-harmonised spectrum was also estimated by inflating network and user terminal costs because of the resulting lack of scale economies in production. Two cases were assessed for non-harmonised additional spectrum using the parameter assumptions detailed in Table 4-6.

Table 4-6: Impact of non-harmonised spectrum

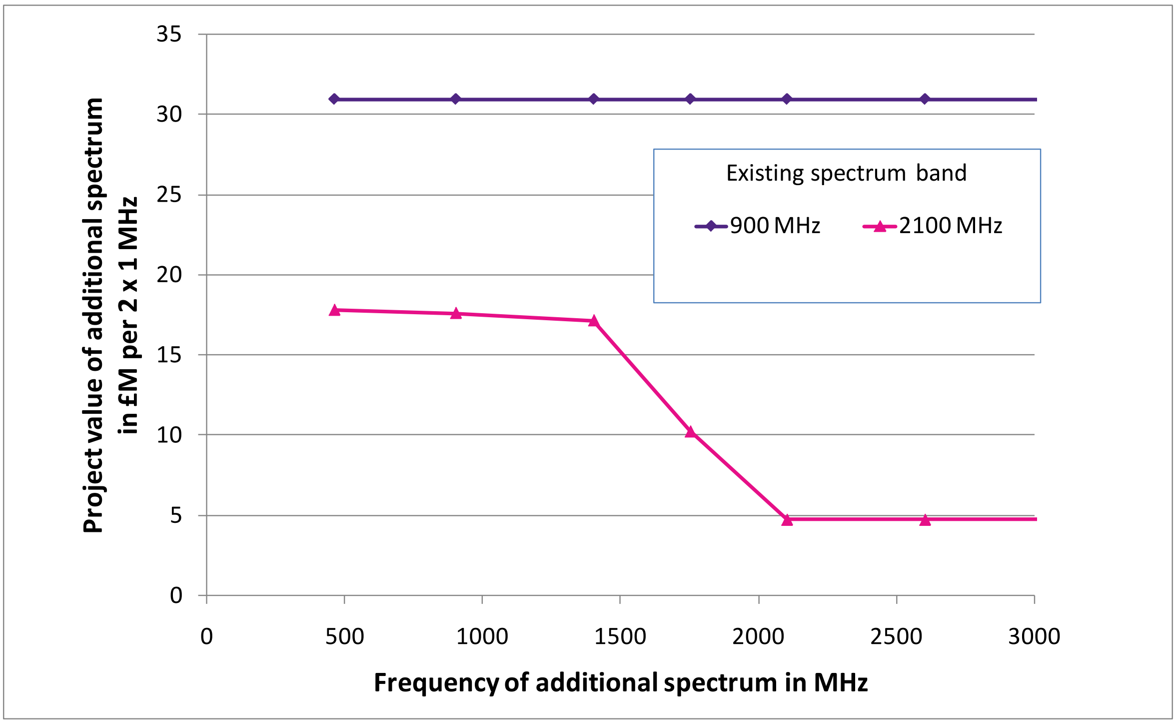
Parameter	Low case	High case
Increase in site upgrade costs	50%	50%
Users requiring non-harmonised terminals	15%	10%
Cost premium for handsets	£15	£25

The parameter values in Table 4-5 and Table 4-6 are varied over a credible range of values intended to illustrate overall impact of such variation on project based spectrum valuation. It is quite possible that a wider range of individual parameter values may occur in practice and indeed more parameters will vary such as extent of rollout, equipment costs and cost of capital.

4.3.1 Variation according to the existing frequency band and additional spectrum frequency

In the mid-scenario, the variation in spectrum valuation is shown in Figure 4-3 according to the frequency band of existing spectrum holdings.

Figure 4-3: Cost reduction spectrum value variation by existing frequency band – mid scenario (expressed in terms of average value per 2 x 1 MHz)



Source: Plum analysis

It can be seen that for additional spectrum at frequencies equal to and above the existing frequency of operation, the benefit comes from increased capacity per site and this is independent of the frequency of the additional spectrum. The value is higher for the existing 900 MHz operator because more of the existing network is capacity limited when the cell ranges are longer. For additional spectrum below the existing frequency similar benefits are obtained in capacity limited areas, but there is an additional benefit in coverage limited areas due to the longer range enabled by the new frequencies. Where the existing frequencies are high, this benefit can be substantial.

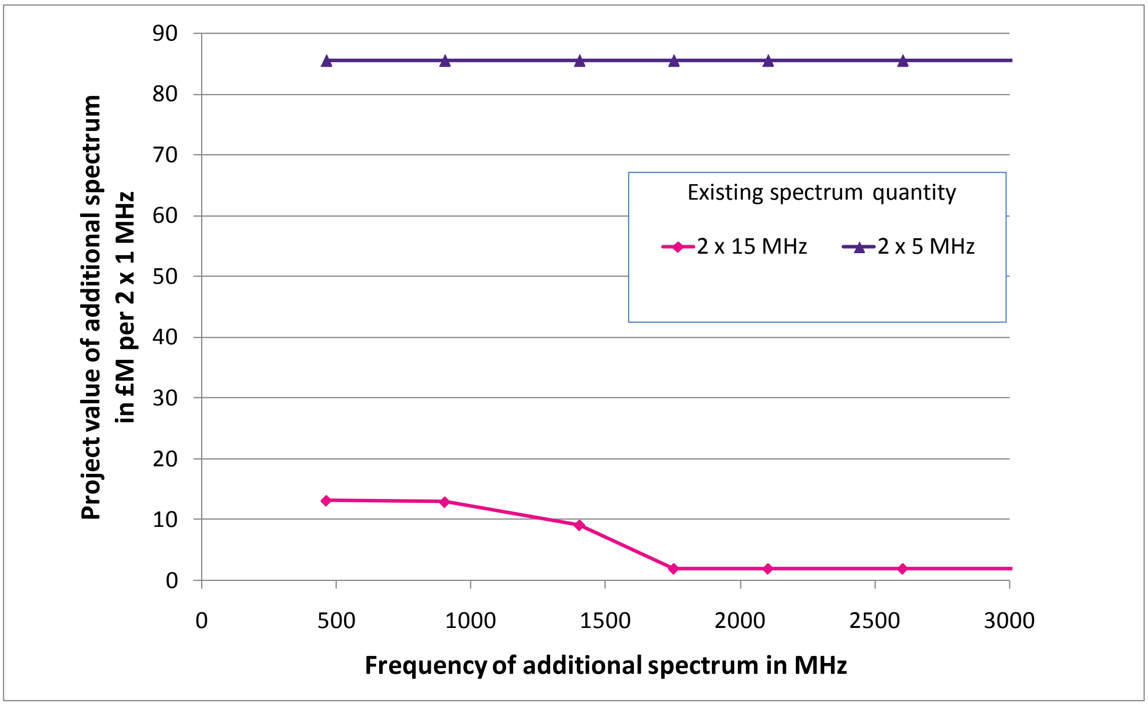
For the other parameters varied, the existing frequency band was set to an intermediate value of 1750 MHz.

plum

4.3.2 Variation with quantity of existing spectrum holdings and additional spectrum frequency

The existing quantity of spectrum was varied from the mid scenario value of 2 x 10 MHz and the results are shown in Figure 4-4. The results show that the amount of existing spectrum held by the MNO has a significant impact on the potential value of the spectrum. This is because the more spectrum currently held by an MNO, the fewer base station sites within the network that are capacity limited (and would therefore benefit from having additional spectrum).

Figure 4-4: Cost reduction spectrum value variation by existing spectrum quantity – mid scenario and existing holdings at 1750MHz (expressed in terms of average value per 2 x 1 MHz)



Source: Plum analysis

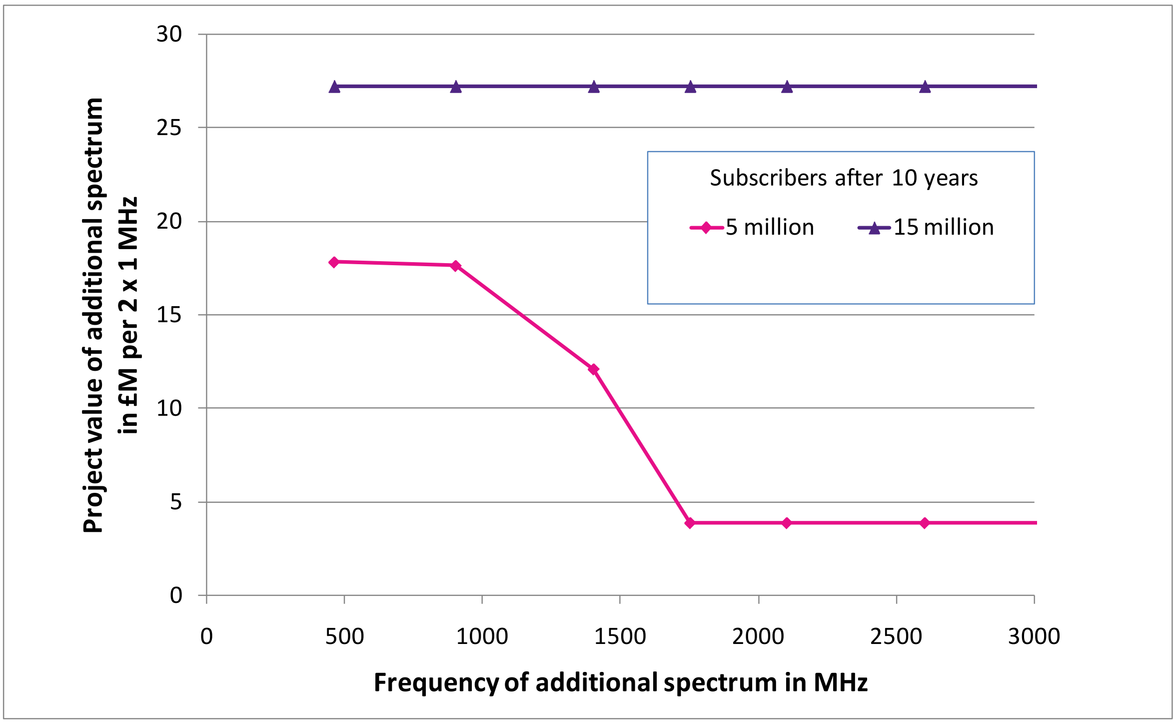
4.3.3 Variation with subscriber growth and additional spectrum frequency

The number of subscribers at the end of the 10 year period was varied from the mid scenario value of 7.5 million to a low value of 5 million (zero subscriber growth), and to a high value of 15 million. The results are shown in Figure 4-5. The results show that subscriber growth has a significant impact on potential spectrum value since it increases the capacity demanded from the network.

With no subscriber growth, the value of spectrum is modest and relies on traffic growth per user to generate value at additional frequencies higher than the existing spectrum, although the coverage benefits still apply at lower additional spectrum frequencies.

With higher subscriber growth, the entire network is capacity limited and the cost reduction savings are higher. At additional frequencies lower than the existing spectrum, sites remain capacity limited therefore the additional spectrum does not provide further coverage benefits.

Figure 4-5: Cost reduction spectrum value variation by final subscriber numbers – mid scenario and existing holdings at 1750MHz (expressed in terms of average value per 2 x 1 MHz)

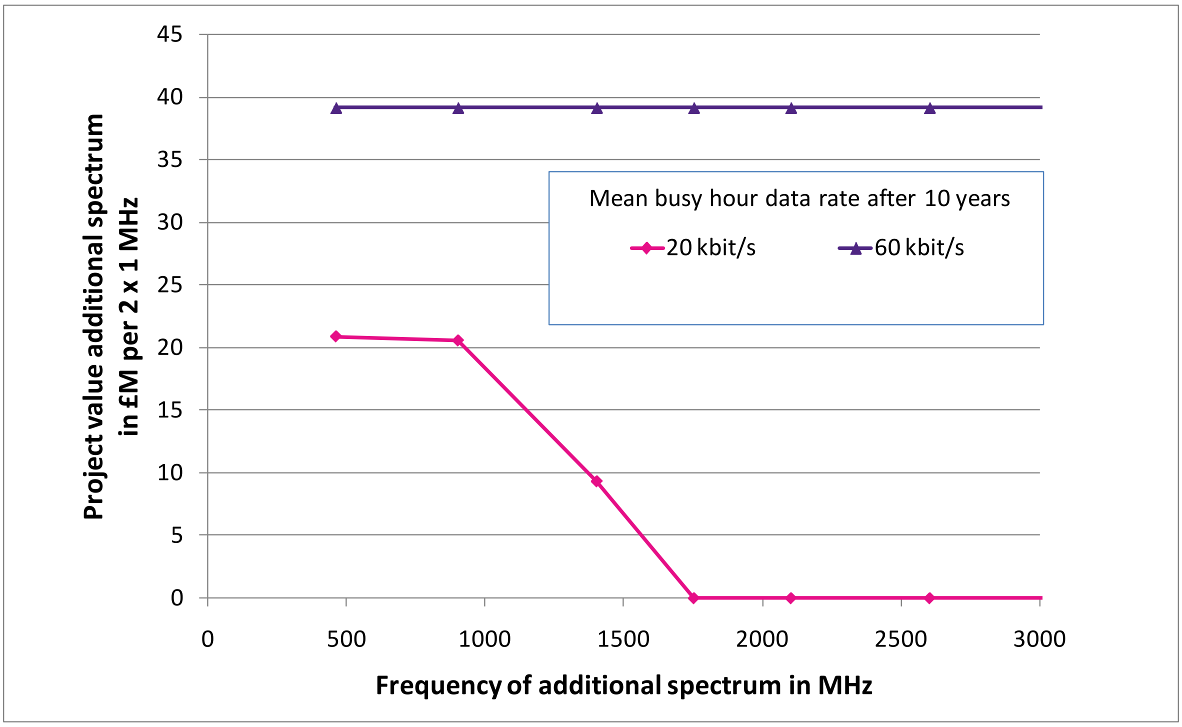


Source: Plum analysis

4.3.4 Variation with data growth and additional spectrum frequency

The growth in average busy hour data rate per user was varied from the mid scenario value at the end of 10 years of 40 kbit/s to a low value of 20 kbit/s and a high value of 60 kbit/s. The results are shown in Figure 4-6. This shows that data growth also has a significant impact on the potential value of the spectrum. Like subscriber growth, data growth increases the amount of traffic carried by the network and therefore there is a higher proportion of sites that are capacity limited and would therefore benefit from having additional spectrum.

Figure 4-6: Cost reduction spectrum value variation by data growth – mid scenario and existing holdings at 1750MHz (expressed in terms of average value per 2 x 1 MHz)



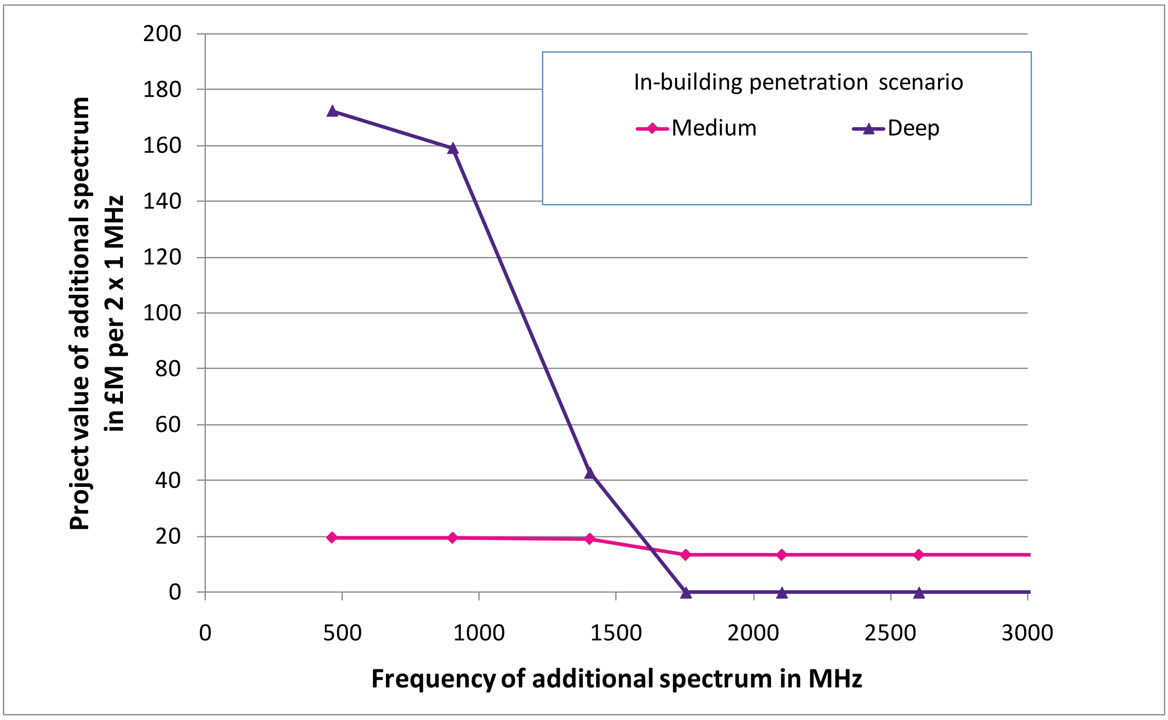
Source: Plum analysis

4.3.5 Impact of deeper in-building penetration

One of the benefits of additional spectrum can be to enable deeper coverage within buildings where the additional spectrum is lower in frequency than the existing spectrum holdings. We modelled the deeper in-building coverage by applying an additional 13 dB of building penetration loss to the link budget from which the cell range was calculated for the mid scenario. Increasing building penetration to this extent dramatically reduces the cell range and therefore many more sites are required.

The impact of this change can be seen in Figure 4-7 where the deeper in-building coverage scenario is compared with a medium level of in-building coverage consistent with present network deployments as assumed for the mid scenario. It can be seen that where the additional spectrum is above the existing frequency, there is no additional value. This is because the higher density of sites required to provide coverage provides sufficient capacity to meet forecast traffic demands without additional spectrum. However at additional spectrum frequencies below the existing frequency, cell range is improved and fewer sites are required. The very high number of sites required for deeper in-building coverage means that such savings can be substantial.

Figure 4-7: Cost reduction spectrum value variation by depth of in-building penetration – mid scenario and existing holdings at 1750MHz (expressed in terms of average value per 2 x 1 MHz)



Source: Plum analysis

4.3.6 Impact of spectrum harmonisation

Harmonisation of the additional spectrum with other mobile networks internationally is important for some of the above value to be practically achievable, since the network costs used in the calculations are based on large scale economies in equipment supply. We note that, as pointed out in a previous report, "the success or otherwise of European harmonisation and standardisation measures depends on a variety of factors, many of which are difficult to anticipate, and on the specific attributes of the service, technology and frequency bands under consideration"[34]. Therefore the harmonisation of frequencies by regulatory authorities is not sufficient alone to generate scale economies. The impact of spectrum harmonisation discussed here is where the market takes advantage of such harmonisation by offering services in multiple countries using the spectrum.

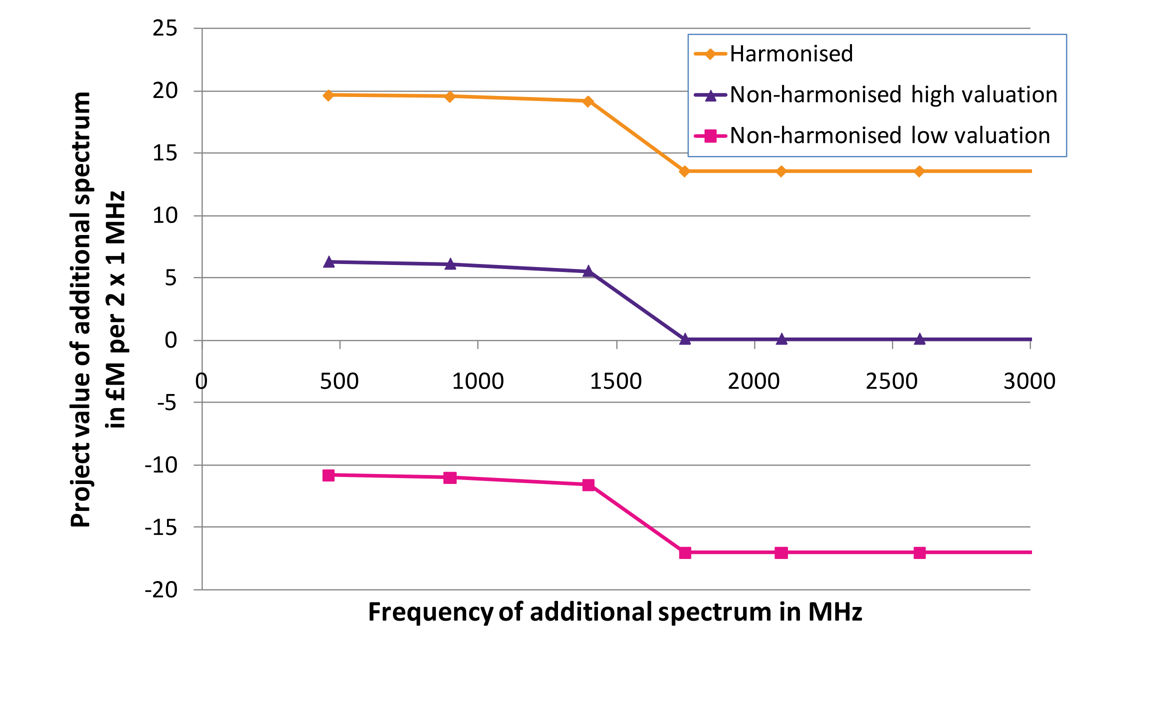
Harmonisation of this additional spectrum is not required for maintaining roaming revenue so long as operators already have access to sufficient harmonised spectrum. However, to make use of the additional spectrum a significant proportion of terminals need to be multiband. If the spectrum is not harmonised then these terminals will be at higher cost which would also need to be borne by the MNO, as an increased subsidy to new and churning subscribers.

To assess the differences between harmonised and non-harmonised additional spectrum we have applied additional costs to network equipment and subscriber terminals where the spectrum is not harmonised. The additional cost depends upon the size of these unit cost increases and the number of

[34] *Costs and Benefits of Relaxing International Frequency Harmonisation and Radio Standards"* by Indepen and Aegis Systems, March 2004 http://www.ofcom.org.uk/research/radiocomms/reports/framework/harmonisation/

subscribers that must be capable of using the additional spectrum to ensure that the additional capacity per site is usable. The project value of additional spectrum based on these assumptions is shown in Figure 4-8. The non-harmonised low and high valuations are based on varying the number of subscribers facing higher terminal costs and the size of unit terminal cost increases.

Figure 4-8: Cost reduction spectrum value variation by spectrum harmonisation – mid scenario and existing holdings at 1750MHz (expressed in terms of average value per 2 x 1 MHz)



Source: Plum analysis

It can be seen that the analysis of project value generates a considerable range of values which are negative for the more pessimistic assumptions in respect of non-harmonised spectrum and a small proportion of the value of the harmonised spectrum under the more optimistic scenario. Again these are based on example ranges of input parameters intended to illustrate the range of valuation that might result.

4.4 Ofcom valuations

Ofcom has sought to derive the value of different frequency bands used for cellular mobile services in the context of setting mobile termination rates[35] and determining the value of liberalised 900 MHz spectrum. [36] In the case of setting mobile termination rates Ofcom was seeking to estimate the marginal forward looking opportunity cost of spectrum at 2.1 GHz. Ofcom and industry proposed several different valuation approaches though in the case of some operators cost recovery was also

[35] www.catribunal.org.uk/files/CC_determination_1083_H3G_1085_BT_220109.pdf.
[36] www.ofcom.org.uk/consult/condocs/spectrumlib. Sections are 4 and 6, and annexes 10, 13 and 15.

seen as an important objective. Valuation approaches considered involved the use of market benchmarks and included:

- Using UMTS auction fees from 2000: These fees were adjusted to take account of changes in market conditions since 2000, reflected partly in the write down of the auction value in O2's accounts. Ofcom also noted that the auction values reflected average not marginal values and so some downward adjustment would be required to obtain a forward looking incremental value.
- Values based on econometric analysis of the determinants of values revealed in auctions of this spectrum in the UK and elsewhere: The Competition Commission concluded the analysis not sufficiently robust, because of uncontrolled differences between auction situations, to provide a foundation for reaching conclusions concerning spectrum value.

The two year debate over the value of 3G spectrum in the context of mobile termination rates highlights the difficulties in using market data that are revealed in specific market circumstances that are not very similar to the circumstances for which values are sought.

In the case of the work on spectrum liberalisation Ofcom calculated the cost savings from having a 2x5 MHz block of 900 MHz liberalized spectrum for a 3G operator that initially has no 900 MHz spectrum (i.e. initially spectrum at 2.1 GHz to provide service and later 800 MHz spectrum may be available). Cost differences arise from differences in the number of sites deployed to achieve a given level of service. The results varied depending on the various assumptions made, including the demand scenarios, the operator's deployment strategy and whether the area served is densely populated or not. In densely populated areas Ofcom estimated the NPV of cost differences to be of the order of £50-250M for 2 x 5 MHz in a low demand/shallow in-building penetration scenario and £1-2.2bn for a high demand/deep in-building penetration scenario. In less densely populated areas the NPV of cost differences was estimated to be in the range £20-60m.

The Ofcom results from the liberalisation work use the public policy discount rate of 3.5%. Translating this to a10% discount rate and adjusting for spectrum quantity, the results equate to £7M and £224M per 2x1MHz for the low and high demand scenarios. Our modelling for a 2100 MHz operator in a high demand/deep penetration case suggests a value of £220M per 2x1 MHz and for the low demand/medium penetration case £30M per 2x1 MHz. Although the key parameters used for our analysis are similar to those used for Ofcom's analysis, the results illustrate how different valuations can result from varying many more parameters (as Ofcom did) than we did for the purposes of this report. The wide ranges of these results confirms the strong dependence of valuations on the specific circumstances of the spectrum buyer and the buyers' expectations of market conditions, even when revenue expectations are not taken into account.

4.5 Conclusions on cellular spectrum value

Although it is possible to model cellular spectrum value, models are complex and require a large number of assumptions.

- Some assumptions can be made with reasonable confidence (e.g. unit equipment costs).
- Some assumptions are reliant on the current assets and operations of the MNO (number of sites, subscribers and usage per subscriber). With few existing MNOs and considerable variability in market share and nature of their subscriber usage, it is difficult to derive a single set of typical assumptions that is representative of all existing and potential future MNOs.

- Other assumptions are reliant on market forecasts for the mobile sector (ARPU growth and traffic growth). Forecasting the future demand for mobile services over the economic lives of the transmission networks concerned is hugely uncertain and spectrum value depends upon the aspirations and market confidence of individual operators.

The results show spectrum value ranging from zero to £240M per 2 x 1 MHz depending upon the input assumptions. The lowest spectrum values arise with non-harmonised spectrum. Under the low case assumptions, non-harmonised spectrum value for cellular mobile applications is negative when used for capacity enhancement (implying a spectrum value of zero), although it has significant positive value under the high case assumptions. This illustrates the strong preference of the mobile industry for spectrum harmonisation when seeking new bands for advanced services. When used for coverage enhancement, the analysis suggests that non-harmonised spectrum could still have value under the low case assumptions where the additional spectrum is at lower frequencies than existing spectrum holdings.

Varying other individual parameters across reasonable bounds for harmonised spectrum results in a wide range of values. At the higher end of the frequency range where benefits arise from capacity enhancement, values vary from zero to £100M per 2 x 1 MHz The range of values is even greater at the lower end of the frequency range where coverage enhancement (in particular increased in-building penetration) is the major driver; values here vary from £10M to £240M per 2 x 1 MHz. Varying more than one parameter simultaneously could be expected to introduce even greater variability.

To include values arising from new revenue streams would require more assumptions to be made about services not yet offered to mobile markets, including assumptions about service take-up and price. These are even more reliant on the MNO's current assets, market presence and confidence in future mobile markets. It is not possible to present meaningful typical or generic values from such analysis and the use of average values would be misleading. Therefore we have used illustrative input parameters in the cost reduction scenario alone to illustrate the variability in values that may result from analysis.

We do not consider that project based valuation of cellular mobile opportunities is a sound basis for establishing generic spectrum value, but can be appropriate for estimating the potential value of spectrum to individual MNOs providing access to appropriate input assumptions is available.

5 Fixed Point to Point

5.1 Introduction

Fixed point to point links are used by different types of business. These include:

- Individual private firms with multiple sites (e.g. utility companies).
- Communications service providers such as public mobile network operators (PMNO)s (to provide backhaul from mobile base stations).
- Managed communications services operators.

Traditionally these requirements have been met on an ad hoc basis, by acquiring individual assignments from primary supply in designated fixed link bands. Users have traditionally been assigned spectrum in different bands depending upon the location, path length and bandwidth of the link. Users implementing shorter links have been encouraged to use higher frequencies through application of Ofcom's path length policy. Although we might expect a lower frequency assignment to have higher value due to its ability to support a wider selection of path lengths and systems, since the assignment is specific between two points, such flexibility cannot be built into the purchase price of a specific link.

Therefore the purchase price for a specific fixed link assignment will be driven by the availability of spectrum for fixed links between the two specific locations. If an assignment is available for the link from primary supply, then the new user may obtain the licence from Ofcom and implement the link. However a buyer may prefer to purchase the link from an existing assignee since:

- Purchase of the link may provide access to existing towers.
- Equipment may be offered as part of the deal.

The sale of individual links is likely to be limited to relatively few locations that are particularly congested and with routes sufficiently generic to appeal to many users. It is for these reasons that we have calculated commercial value by examining the case of a hypothetical commercially managed fixed link band.

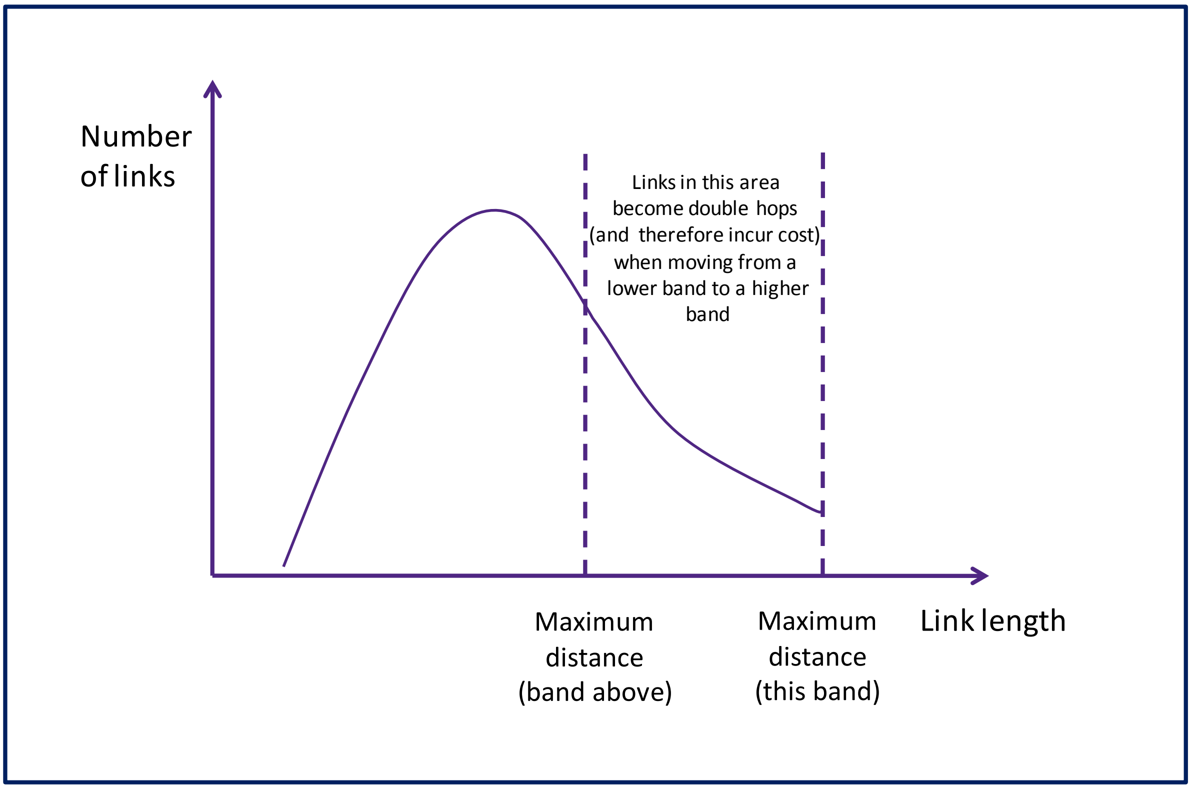
As a managed fixed link band, the buyer would configure the band for fixed link usage and either sub-let the band for individual links or offer managed communications services to the market. We can expect this kind of opportunity to be most attractive to a buyer with an extensive portfolio of sites and their market to be either other communications providers (such as public mobile network operators) or individual business users.

Where spectrum for fixed links is already available at similar frequencies from primary supply (i.e. direct from Ofcom managed fixed links bands), then new fixed links could be accommodated at little cost, and the new spectrum would have little value as a fixed link band. However if the spectrum offered for sale is below a frequency threshold where there is excess demand for fixed link bands, then the new spectrum could attract links which would otherwise be forced to migrate to higher frequency bands or use an alternative communications service (e.g. leased line). The focus of our analysis is therefore on frequency bands for fixed links that are generally regarded by Ofcom as in excess demand.

5.2 Framework for analysis

In general it is thought that the most congested bands are the lower bands, below a threshold of around 20 GHz. In part this reflects the diminished frequency re-use available in lower frequency bands, which reduces the capacity of a given amount of spectrum in these bands. The main value in these lower bands from the user's perspective lies in the ability to attain the longest link distances in a single hop thereby economising on the number of sites and associated equipment on a route. However our analysis of the existing assignments in lower frequency bands shows that only some of the links in these bands would be adversely affected by moving to an uncongested (higher) band, as shown in Figure 5-1.

Figure 5-1: Distribution of desired link lengths in a given frequency band



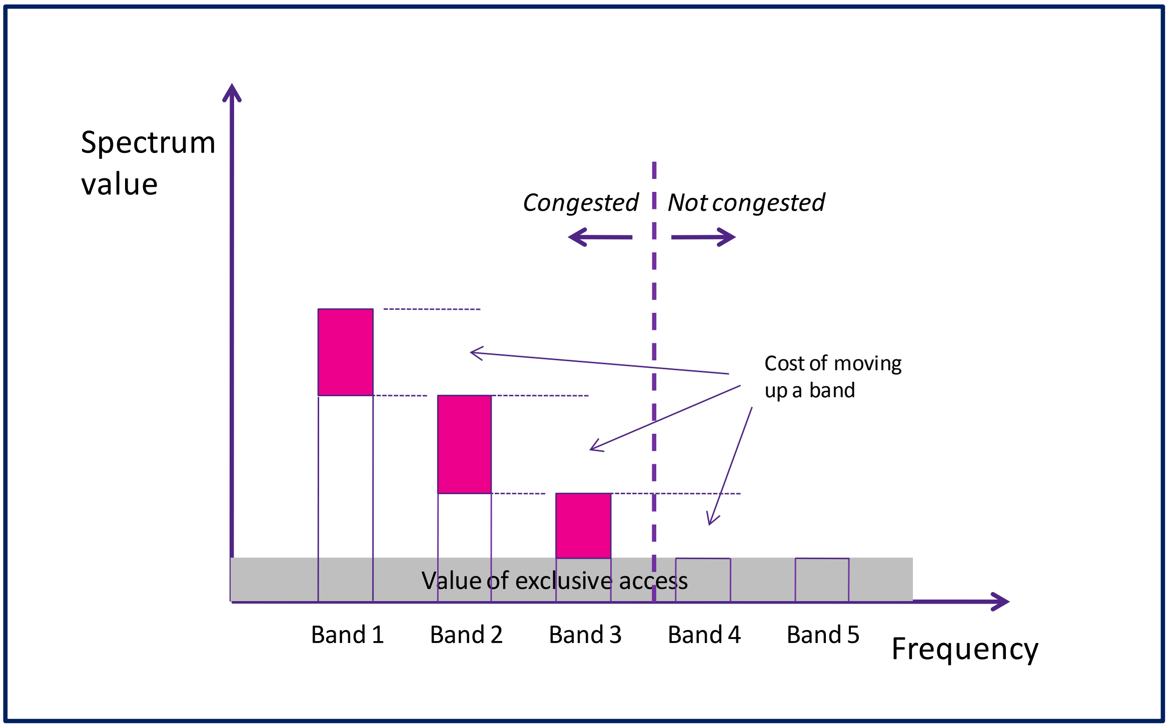
Clearly lower bands are of great value to users wanting to establish long routes and of little value to those users wanting to establish a single short hop. For the latter, there are many higher frequency bands that have a large capacity for short hop fixed links (by virtue of the much higher frequency reuse attainable) and may indeed be cheaper to use (due to smaller antenna sizes). There is little excess demand for these higher frequency bands and this is likely to remain the case for some time. Because of this they do not have the scarcity value associated with bands where there is excess demand but might still have an option value associated with exclusive access.

Focussing on frequency ranges in which there are fixed link bands with excess demand (and putting aside the fact that the current AIP fee structure has an impact on the demand profile as discussed in section 3.3) we need information on the distribution of existing link lengths to determine the value of such fixed link bands. To value additional spectrum that might be made available in the same frequency range we also need to make assumptions about the link length distribution arising from the demand of potential new users. In both cases we have calculated values based on the existing link length distribution in the bands with excess demand, although we recognise this may be changing as fibre/leased lines have tended to replace long backbone links (as their relative price has fallen) while there has been growing demand for high density short backhaul links particularly in urban areas to support the continuing rollout of 3G mobile networks.

We have calculated the value of spectrum currently used by fixed links according to the additional costs that would otherwise be faced by existing or potential new marginal users to utilise higher frequency bands. In some cases where links are long, a large number of additional hops may be required and it is possible that a leased line or fibre alternative could be cheaper than putting in all the wireless hops associated with higher frequency spectrum, and so our estimates may be on the high side.[37]

We can consider the value of a particular band as the net cost of migrating its fixed links to another band plus the opportunity cost of purchasing spectrum for the second band. The value of that band is given by the net cost of migration of its links to a third band plus its opportunity cost, and so on. Therefore we can build up the value of a band using a model of successive displacement as shown in Figure 5-2. In practice where we are looking at a whole band the additional costs of moving to the next band will be an average across all links, as not all links will require extra hops when the frequency band changes.

Figure 5-2: Incremental spectrum value by frequency band



We have applied the framework developed in Section 2 to the situation shown in Figure 5-2. Suppose the characteristics of Bands 1-4 are as shown in Table 5-1. We assume that the bands only differ in

[37] It is assumed that the costs of leased lines and other substitute services always exceed the costs of moving to another band and that the business does not go out of business if it moves band. If the first assumption does not hold then the least cost alternative places a cap on value and if the second assumption does not hold then viability places a cap on value. The values we calculate provide an upper bound on these valuations.

terms of the link length that can be supported and that all users face costs C of putting in an extra hop (i.e. site, equipment capex and maintenance costs) and face transaction costs T[38] of moving to another band (e.g. costs of removing and installing equipment, costs of dual operation to address installation risks, costs of buying new equipment/retuning existing equipment). We note there is not an effective second hand market in fixed link equipment, partly because of the costs of decommissioning equipment can be significant, and so equipment retired before the end of its life is scrapped. So if a user moves band it will simply incur the costs of buying new equipment earlier than otherwise would be the case.

The maximum commercial value that an hypothetical commercial band manager may be able to extract from the existing users is the most they would be willing to pay to avoid moving (penultimate line of Table 5-1). The marginal value of spectrum in the band is the additional amount the marginal user would be prepared to pay to avoid moving and is as shown in the final line of Table 5-1.

These calculations involve many simplifying assumptions but give an indication of how a trader might value fixed link spectrum. In practice users will face similar costs of implementing additional hops in a given location but there will be a distribution of values for T depending on the age of existing equipment and the risks and costs associated with moving which will be organisation-specific.

Table 5-1: Deriving spectrum value: a stylised example for fixed link bands[39]

	Band 1	Band 2	Band 3	Band 4
Bandwidth	1 MHz	1 MHz	1 MHz	1MHz
Status	Congested	Congested	Congested	Uncongested
Number of extra hops to move to next band	One	One	One	n.a.
Number of users	15	14	12	10
Number of users who need extra hop (s) to move to next band	5	3	2	n.a.
Cost of an extra hop	C	C	C	n.a.
Net transaction costs associated with moving	T	T	T	T
Max value per MHz	V1 = 15T+5C+ V2+ V3	V2 = 14T+3C+ V3	V3 = 12T+2C	0
Marginal value of capacity for one link	T if there are some users who do not need extra hops to move to next band C+T if all users need extra hop	T if there are some users who do not need an extra hop to move to next band C+T if all users need extra hop	T if there are some users who do not need an extra hop to move to next band C+T if all users need extra hop	0

[38] As with c this cost is assumed to be an NPV

[39] This assumes the costs of spectrum management recovered from each licensee are zero. If these costs were constant and non-zero, say K, then the value of each band would be increased by the amount K.

Now suppose a new (harmonised) fixed link band is offered to the market to hypothetical commericial band managers by Ofcom that is comparable to Band 2 and there is competition to buy this band because it is available to meet future demand from end users who would otherwise have to use the uncongested band and incur additional costs in doing this. If the new band is assumed to have capacity for 15 links and demand for these from new end users arrives linearly over say a 10 year period then (assuming both the users and the commercial band manager have a common 10.5% discount rate) then maximum value of the band would be approximately 9C.

What this stylised example shows is that the marginal and average value of the bands with excess demand depends on the link lengths that users require and the transaction costs they face in moving. We need to have a good understanding of current and likely future spectrum use to identify the average and marginal costs concerned (as well as the dynamic responses of users in an environment where some links in some bands are already charged AIP fees to reflect historic expectations of excess demand). In particular we need information on link lengths and the age of the equipment in the bands.

5.3 Model parameters

Our engineering and commercial model relating to Fixed Links includes the parameters listed in Table 5-2.

Table 5-2: Parameters used for the Fixed Link modelling

Parameter	Value
Total number of links	Investigate Ofcom measures of band capacity
Geographic distribution of links	Ofcom aggregated data for specific frequency bands
Locations congested (Note 1)	Approximate proportion of links within congested areas
Hop length distribution	From Ofcom assignment database
Maximum hop length in "higher" band	Based on availability requirements and propagation behaviour
Number of original hops requiring one or more additional hops when moved to "higher" band	Calculated from analysis of band data
Equipment cost assumptions	Equipment suppliers
Network maintenance	Percentage of cumulative capex
Site rental	Local sources
Cost of capital (pre-tax real)	10.5%[40]

Note 1: In the event we addressed the links in each frequency band on a national basis.

[40] The Ofcom March 2007 Statement on Mobile Call Termination estimates a range for MNOs' WACC of 9.7% to 13.2%. We have used this range as indicative of the wireless sector, with a value from the lower end of this range for Business Propositions based on cost reduction or operations support.

Ofcom made available information from which we were able to create a distribution of link lengths. This is discussed in the next section.

5.4 Link lengths

Ignoring local factors such as ground and antenna heights, the general factors that determine the maximum link length that can be achieved in a particular frequency band are the signal level required at the receiver and the link availability needed. The receive signal level in turn is directly linked to the bitrate and modulation efficiency both of which determine the channel bandwidth. For a given frequency band a high bitrate (e.g. 155 Mbps) link based on efficient modulation (e.g. 64-QAM) and using a 28 MHz channel will therefore have a much shorter maximum link length than a low bitrate (e.g. 8 Mbps) link based on a less efficient modulation (e.g. QPSK) and using a 7 MHz channel.

For the nine fixed link bands between 1 and 23 GHz, namely 1.4 GHz, 4 GHz, lower 6 GHz, upper 6 GHz, 7.5 GHz, 13 GHz, 15 GHz, 18 GHz and 23 GHz, the links in each band have been placed into nine groups based on three required receiver signal level ranges and three availabilities (for each signal level range) as follows:

- Required receiver signal level range
  - -133 to <-110 dBW
  - -110 to <-100 dBW
  - -100 to -85 dBW
- Availability
  - 99.9%
  - 99.99%
  - 99.999%

Where link availabilities in the Ofcom assignment database do not exactly match the three levels indicated above they have been grouped into the next highest category (e.g. 99.996% is placed in the 99.999% grouping).

A number of fixed links in the database do not have a Service Code or Service Description and it has therefore not been possible to assign them to one of the above nine signal level / availability groups. They have therefore been omitted from the analysis. The quantities used and those omitted are indicated in the table below.

Table 5-3: Number of links and bandwidth by fixed link frequency band

Frequency band	1.4 GHz	4 GHz	Lower 6 GHz	Upper 6 GHz	7.5 GHz	13 GHz	15 GHz	18 GHz	23 GHz
Total bandwidth	48 MHz	540 MHz	474 MHz	640 MHz	448 MHz	448 MHz	224 MHz	1904 MHz	1176 MHz
No. of links included	909	57	245	425	1016	4112	1440	6730	5387
No. of links omitted	26	0	0	0	1	0	491	2197	188
Total No. of links	935	57	245	425	1017	4112	1931	8927	5575

The first point to note here is the very small number of links in the 4 GHz band. On the face of it this band does not appear to have excess demand[41]. We understand from Ofcom that a number of wide bandwidth legacy links have left the band recently partly in response to spectrum pricing. The 6 GHz bands also look lightly used relative some of the upper bands however there may be excess demand on specific routes. The data are not sufficiently granular to identify whether this is the case or not.

For each signal level / availability group in each of the above nine frequency bands, a distribution of implied link lengths is obtained (in 2 km bins up to 100 km with an additional >100 km bin to catch the few links that are greater than 100 km). However, the statistical sample for some groups is too small to be representative and could lead to a smaller maximum link length being assumed than is really the case. In order to eliminate inconsistencies across path lengths the maximum link lengths derived from the data have been adjusted according to three general rules:

- For a particular signal level / availability group, if a link in the frequency band above (i.e. higher frequency) achieves a specific maximum path length then this path length will also be achievable by links in the (lower) frequency band being considered.
- Within a particular signal level group and for a particular frequency band, if a link having higher availability achieves a specific maximum path length then this path length will also be achievable by links having the (lower) availability being considered.
- Within a particular availability group and for a particular frequency band, if a link with a requirement for a higher received signal level achieves a specific maximum path length then this path length will also be achievable by links requiring a lower received signal level being considered.

On this basis we have derived a consistent set of maximum path lengths (km) as shown in Table 5-4.

[41] In comparison with the band above (the Lower 6 GHz band) the 4 GHz band has a greater total bandwidth available and yet only a quarter of the number of links. It is recognised that frequency reuse will be lower in the 4 GHz band but this difference will be marginal.

Table 5-4: Estimated maximum path lengths

Receive Signal Level	Availability	1.4 GHz	4 GHz	Lower 6 GHz	Upper 6 GHz	7.5 GHz	13 GHz	15 GHz	18 GHz	23 GHz
Low	99.900	>100	>100	>100	>100	>100	70	46	34	30
Low	99.990	>100	>100	>100	>100	>100	70	46	34	30
Low	99.999	88	88	88	88	82	40	24	24	14
Medium	99.900	96	96	96	96	96	58	42	34	30
Medium	99.990	96	96	96	96	96	58	42	34	30
Medium	99.999	88	88	88	88	64	40	24	24	14
High	99.900	96	96	96	96	96	46	40	34	22
High	99.990	96	96	96	96	96	42	40	34	22
High	99.999	88	88	88	88	64	30	14	10	8

We next determined the number of hops each link would require if it was moved to the next highest band, on the assumption that this triggered movement all away along the chain as shown in Figure 5-2.

Applying the maximum path lengths attributable to the band above the frequency band being considered we have calculated the number of links in a band that would require a double hop if links were to be moved up a frequency band. This is shown in Table 5-5. As can be seen relatively few links in each band require additional hops when moving to the next band.

Table 5-5: Numbers of links requiring additional hop(s) when moving up to the next band

RSL	Availability	1.4 GHz	4 GHz	Lower 6 GHz	Upper 6 GHz	7.5 GHz	13 GHz	15 GHz	18 GHz
Low	99.900	0	0	0	0	9	0	0	0
Low	99.990	0	0	0	0	6	5	2	0
Low	99.999	0	0	0	0	12	14	0	8
Medium	99.900	0	0	0	0	2	1	1	0
Medium	99.990	0	0	0	0	4	16	11	0
Medium	99.999	0	0	0	0	9	22	0	14
High	99.900	0	0	0	0	41	1	0	0
High	99.990	0	0	0	0	38	2	1	1
High	99.999	0	0	0	4	2	11	2	2
Total		**0**	**0**	**0**	**4**	**123**	**72**	**17**	**25**
Total links		909	57	245	425	1016	4112	1440	6730

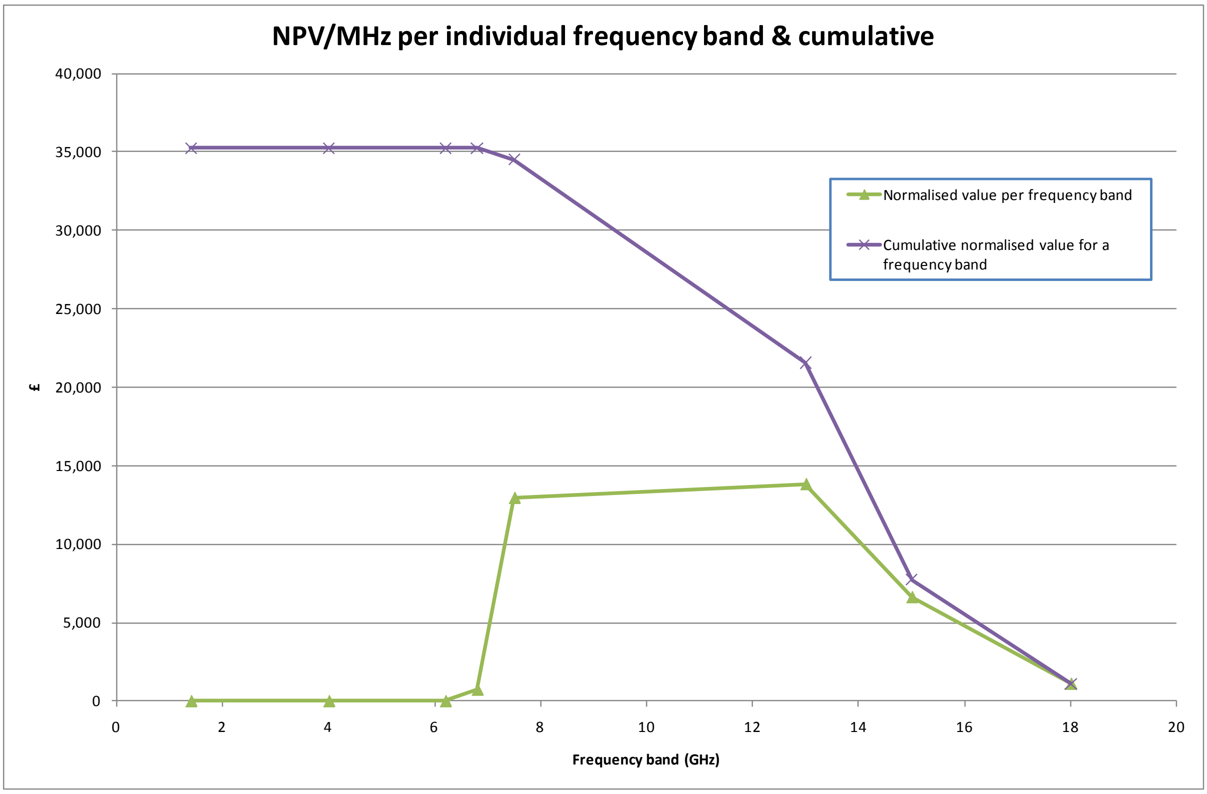
5.5 Calculating values

5.5.1 Currently occupied bands

Leaving aside transaction costs the maximum total value of each band can be calculated based on the costs of additional hops for the affected links in the band – i.e. the NPV of equipment, site and maintenance costs. To do this we have to make assumptions about asset life and discount rate. We assume a 15 year asset life and a 10.5% discount rate. Equipment costs are roughly the same at and above 8 GHz (and within the range of frequencies above 8 GHz we are considering here) but there is an equipment cost premium of some 30% for equipment operating below 8 GHz.

The resulting values per MHz are as shown in Figure 5-3. As can be seen the value per MHz is constant at around £35k/MHz for the lower frequency bands until it starts falling for higher frequencies from 7.5 GHz reaching a low value of slightly more than £1k/MHz for the 18 GHz frequency band.

Figure 5-3: Value per MHz <u>for congested bands</u> based on costs of extra hop when migrating to next highest band



The values forming the lower of the two curves in Figure 5-3 are the additional cost of migrating fixed links in a given frequency band to the next highest frequency band. These values are represented by the shaded portion at the top of each histogram bar shown earlier in Figure 5-2.

The values forming the upper of the two curves in Figure 5-3 are the value of each frequency band obtained by accumulating the additional costs starting from the uncongested threshold (i.e. 20 GHz) where the value is zero. These values are represented by the whole of each histogram bar shown earlier in Figure 5-2.

The values will increase of course if transaction costs are added and the increase could be significant as the transaction costs apply to most or all links in the band not just those that would require an additional hop when moving to the next band.

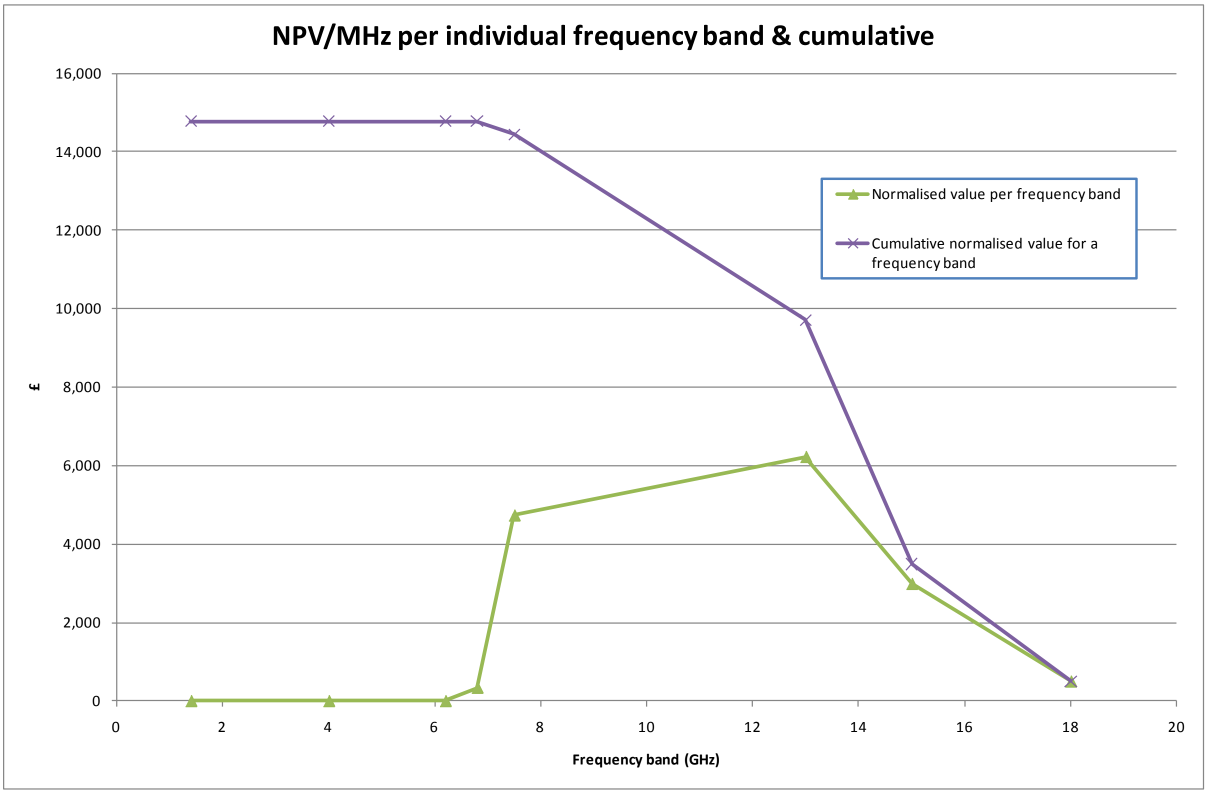
5.5.2 New frequency band

What if a new frequency band was offered to the market? To estimate its potential value we assume:

- The band attracts new demand with a similar length profile to that of nearby fixed link bands.
- The band is harmonised and so equipment costs for existing similar bands can be assumed.
- Users have the alternative option of moving to a higher band with equivalent available capacity.

The value then depends on the time profile of demand. We assume that the band is filled evenly over a 15 year time frame.[42] The band manager's licence may have a term that exceeds 15 years and so a terminal value should apply. We have assumed the terminal value is zero, implying our estimates understate the commercial value of the spectrum. The new values are given in Figure 5-4.

Figure 5-4: Value per MHz for additional spectrum based on costs of extra hop when migrating to next highest band



[42] We have assumed no terminal value for the spectrum

As before the lower curve in Figure 5-4 above is the additional cost associated with link migration for each frequency band, and the upper curve is the value of each frequency band obtained by accumulating the additional costs starting from the uncongested threshold where the value is zero – refer to Figure 5-2 earlier for the principle.

If the new band is not harmonised then the value will be less than that if the band were harmonised. It will be reduced by an amount related to the higher costs of equipment. Table 5-6 shows the additional cost of a single link (using typical bandwidths for different link types) in a non-harmonised band. This is based on information from an equipment supplier that suggests a 50% equipment cost premium for non-harmonised equipment. We note that this implies a total cost premium for a link in a non-harmonised band of 14-23% because site costs and installation costs are assumed to be unchanged.

Table 5-6: Additional costs for a single link when using non-harmonised band

Frequency range	Link type	£ NPV per MHz	£ per annum per MHz
Below 8 GHz	Low (7 MHz BW)	2044	250
	Medium (14 MHz BW)	1402	172
	High (28 MHz BW)	954	117
Above 8 GHz	Low (7 MHz BW)	1493	183
	Medium (14 MHz BW)	1038	127
	High (28 MHz BW)	714	87

From our previous (cumulative) results given in Figure 5-3 the value of the 10 GHz band is £28,000 per MHz for all links, or equivalently £280 per MHz (as an NPV) for a single link assuming reuse of 100. For a single link, the additional cost associated with using non-harmonised spectrum expressed as an NPV falls in the range £714 per MHz to £1493 per MHz depending on the link type. The non-harmonised additional cost is approximately two and a half to five times greater than the value were it to be harmonised. The non-harmonised spectrum therefore has no value.

5.6 Comparison of values

Table 5-7 gives estimates we have produced for the 7.5 GHz band (as an example) and we have compared this with an auction value at 10 GHz and AIP values currently applied by Ofcom at 7.5 GHz and in higher frequency bands. The AIP values in the table have been expressed in a comparable NPV/MHz assuming a frequency reuse factor of 100[43] and a 15 year time frame. Two 'AIP' figures are presented; one, where all the links are introduced into the band in the first year, and the other, where the links are introduced into the band gradually over the 15 year time frame. This allows for a comparison with our derived estimates.

As can be seen the values we have obtained seem high compared with the auction value, but it needs to be remembered that the value of this band is reduced by uncertain MOD activity and the fact that even though there is a band plan, equipment manufacturers do not consider it harmonised in terms of

[43] While this is representative for the two lower frequency band examples here (i.e. 7.5 GHz and 10 GHz) it is arguable that it should be greater for the higher frequency band example (38 GHz).

making equipment available for civil use. As noted above, non-harmonisation can potentially remove all value from unmanaged spectrum in a given fixed links band. In fact if the auction price of £3k/MHz is compared with Ofcom's fees in the uncongested 38 GHz band one might be tempted to conclude the band has little value as unmanaged spectrum (as suggested in the previous section) as the bidders gain a £2.3k saving in avoiding paying fees to cover Ofcom's administrative costs (though they will incur their own spectrum management costs).

In terms of comparison with AIP values expressed as an equivalent NPV/MHz, it can be seen that the values we have obtained are approximately double the equivalent AIP values. This is broadly consistent with the fact that AIP fee rates were was set at half or less the calculated opportunity cost in 1998.

The wider question raised by examination of the values in Table 5-7 is: are the frequency bands we have been valuing likely to experience excess demand under the existing fee structure? Casual examination of the number of links in each band suggests potentially not, but more detailed analysis of future demand would be required to substantiate this. If the bands are likely to continue to have spare capacity and there are no other competing uses for the spectrum then it is possible that the existing prices should be set at lower levels to encourage a better balance of supply and demand in the longer term. In this regard we note that the 4GHz band looks particularly lightly used and we understand this is because a major user has left the band motivated in part by the level of spectrum fees. However, unlike some of the higher frequency bands, this particular band could in future also be used by mobile applications (perhaps initially on a non-harmonised basis) which suggests that any regulatory pricing should have regard to this possibility.

Table 5-7: Different measures of spectrum value for some fixed link bands

Measure	Value/MHz (£)	Comments
Estimated value of existing spectrum to commercial band manager at 7.5 GHz given existing demand	35k	Derivation excludes band manager spectrum management costs and assumes sustained excess demand
Estimated value of additional spectrum to commercial band manager at 7.5 GHz given existing demand	14k	Derivation excludes band manager spectrum management costs and assumes some excess demand for much of licence term
10 GHz auction	3k	Excludes spectrum management costs, allowance for MOD use in band, usage assumptions unknown, not fully harmonised for civil use so equipment cost premium
Existing AIP* at 7.5 GHz for 100 links – immediate vs gradual use of the band	21k/6.6k	Includes Ofcom's spectrum management costs
Existing AIP* at 10 GHz for 100 links	12.5k/3.8k	Includes Ofcom's spectrum management costs
Existing fee at 38 GHz for 100 links	7.5k/2.3k	Only contribution to Ofcom's spectrum management costs

* Note AIP fee rates were set at half or less the calculated opportunity cost in 1998

5.7 Conclusions

The analysis in this section points to the following conclusions:

- Ofcom has data on link length and numbers of licensees and this has allowed us to calculate commercial values of spectrum for currently occupied bands and for additional spectrum, given existing observed levels of demand. The additional spectrum has values around half those of the currently occupied spectrum, assuming future levels of excess demand are moderate.
- Lower frequency bands appear to be significantly more valuable than higher ones, but non-harmonised bands have little if any value. The latter is confirmed by both our calculations and a recent auction result for a relevant band.
- Many of the fixed link bands are unlikely to experience excess demand across the UK but instead to experience excess demand focused on specific locations and/or along key specific routes. However our analysis has not examined this aspect of value variation. The most appropriate way to reflect commercial band value on a geographic basis is an issue which requires further detailed analysis that is beyond the scope of this study.
- To value spectrum with more certainty more comprehensive information would be needed in the areas of the distribution of desired link length, the extent of existing and likely future excess demand at different fee rates, users' choices and the transaction costs they face if vacating spectrum – in particular relating to the costs of decommissioning existing equipment and sites.

6 Single Site deployments

6.1 Introduction

Private Business Radio (PBR) users are distributed through towns, cities and rural areas in the UK where use of the spectrum fulfils a business need for communications between employees. Most firms use PBR communications because of its ability to provide reliable press-to-talk, closed user group communications at low cost. For wide area users, it also provides low cost coverage because of its long distance propagation characteristics.

Licensees generally have a local region of desired coverage, corresponding to the area in which they undertake most of their business. They may attach a small value to larger coverage than this (on the basis of occasional use) particularly as the availability of good mobile phone coverage means that mobile phones may be a more effective fallback. Our model encompasses the following PBR business propositions.

- Wide area exclusive users (such as utility companies). Wide area users may also be regional (e.g. local authorities).
- Local area individual users (single site exclusive area).
- Common Base Station (single site providing service to multiple users on a subscription basis).
- Local area shared frequencies (multiple users, time shared using CTCSS or DCS).

PBR licensees' choice of frequency will be typically dictated by:

- Operational needs
  - Hand portable users (licensees having a fleet of portables) will generally prefer UHF frequencies (due to the smaller antennae and more compact handsets that are available for this spectrum)
  - Vehicular users (licensees having a fleet of vehicles) are able to use both VHF and UHF frequencies
- Operational costs
  - Hand portable users are likely to attach little or no additional value to VHF frequencies
  - Some vehicular users will have coverage requirements easily achieved using either VHF or UHF frequencies and will therefore be indifferent to VHF or UHF
  - However other vehicular users may attribute higher willingness to pay for VHF frequencies due to their lower deployment costs where large coverage areas are required

This discussion revolves around VHF and UHF frequencies to illustrate the motivations of licensees and potential sources of value difference between these frequencies. However, although some regulatory allocation boundaries also reflect this distinction, we need to recognise that the categorisation is to some extent artificial and there is a continuum to be considered in practice for commercial valuation purposes.

Because there are many small users in PBR bands, our approach to valuing spectrum for this service is based on the commercial value that might be extracted by a hypothetical commercial band manager.

6.2 Framework for analysis

Users are willing to pay for access to frequencies that can be used for PBR because of the operating benefits the technology gives to their businesses. Just as with the fixed links modelling discussed in Section 5, all else being equal the commercial value of an already occupied band is likely to exceed that of a new band because incumbent users will generally incur some transaction costs when they move. In this Section we consider in detail the approach to valuing a new frequency band.

We first address the following questions:

- How much would an individual PBR user be willing to pay for access to spectrum?
- How does value vary with base station deployment?
- How does value vary with frequency?
- How does value vary with the level of excess demand?
- What are the implications for an hypothetical commercial band manager's income?

6.2.1 Users' willingness to pay for spectrum access

The deployment of PBR systems meets an internal communications need for a business. The value of this need being fulfilled to the business concerned is in part enabled or enhanced by the communications resource associated with PBR systems along with other inputs. However the availability of mobile phones or, for some users, licence-exempt PBR provides a potential alternative to the use of licensed PBR spectrum to meet the same communication need for many businesses.

Use of PBR is nevertheless preferred over mobile phones because:

- Costs are fixed and known in advance.
- It discourages personal use of the mobile phone.
- Response times are quicker and group calls can be easily initiated.
- It can be integrated with despatch data systems.
- Coverage can be tailored to meet specific needs that might not be as well served by public cellular systems – e.g. to serve underground / basement areas.
- In some cases PBR may be perceived to provide better rural coverage particularly at VHF but we can assume that this is less of an issue for single site PBR systems focussed on local communications. For national networks (e.g. used by emergency networks), the coverage advantage could be more important.

Some PBR features have been added to the GSM standards, for example faster call setup and support of user groups. However, GSM has not been popular with the PBR community since it is not sufficiently fast for many safety critical applications, and PBR coverage and capacity can be more specifically designed for the licensee's requirements. In the longer term improved coverage and functionality of 3G networks operating in the 800 / 900 MHz bands may make public networks a more viable alternative for PBR users.

To understand the economic incentives for using PBR spectrum we can compare the costs of mobile phone charges and PBR systems for a typical licensee as shown in Box 6-1.

Box 6-1: Comparison of mobile phone and PBR costs

Assuming that a licensee has 70 terminals using a single exclusive channel and each terminal contributes a traffic load of 5 mErlangs in the busy hour. Therefore considering the two options:

Mobile phone network

Capex would be handset costs = 70 * £50 (say) = £3,500

Annual mobile phone charges = #users x Erlangs x 60 / (% daily traffic in busy hour) x (working days/month) x 12 x charge/minute
=70 x 5/1000 x 60 / 10% x 20 days x 12 months x charge/minute
= 50,400 minutes x charge/minute

= £5,040 (at 10p per minute)

Estimated annual cost of maintaining and periodically replacing handsets: £20 per user = £1,400 total
Over 10 years discounted at 10% this would equal 6.8 x £6,440 = £43,792 per channel.
Total cost of mobile phone solution is £47,292

PBR system solution

Cost estimates based on ERC Report 105 (2001), updated where necessary:

Capex would comprise base stations and mobile stations

Base station: £1,500 pounds – assume unchanged. Mobile station[44]: £150-250 – assume £150
Total capex: 1500 + (70 x 150) = £12,000

Opex would comprise site rental, electrical power, land line and mobile maintenance

Site rental: £1,000 – assume 50% increase to £1,500 per year
Electrical power: £300 / base station / year – assume double (to reflect energy prices) - £600
Land line: £300 per line – assume down slightly to £250
Batteries, maintenance and periodic replacement of mobiles: £50 per terminal per year – assume down slightly - £40
Total opex = £1500 + £600 + £250 + £(70 x 40) = £5,150 = £35,020 over ten years

Total cost of PBR solution = £47,020

(Note also this calculation does not take any account of PBR licence fees.)

The calculation in Box 6-1 shows that PBR and mobile phone costs may be similar for the traffic levels assumed in the example. However, the actual value to the business is substantially higher than the

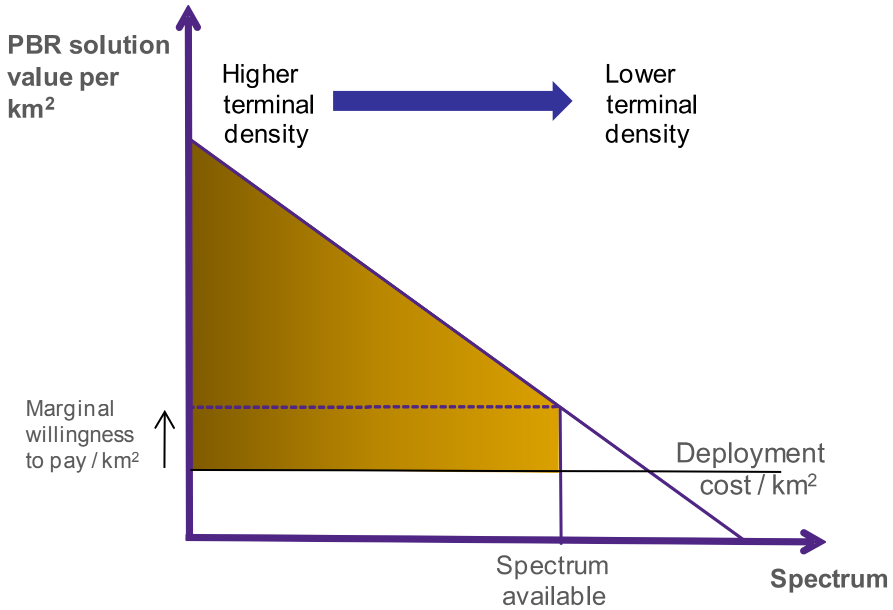
[44] PBR handsets are more rugged than cellular handsets and their functionality changes less. Hence PBR equipment has a longer life (around 10 years) than cellular handsets (3-5 years). While PBR mobiles have a longer life there is the need for occasional maintenance while a cellular handset is likely to be replaced rather than repaired.

cost of PBR deployment or the mobile phone alternative as was apparent in the willingness to pay (WTP) research undertaken by the Radiocommunications Agency in 2000[45]. This estimated consumer surplus for PBR licensees at £95 / terminal / month compared to £47 / terminal / month for GSM business subscribers. This surplus provides a measure of a users' maximum willingness to pay for the service. As the substitute mobile functionality has increased and monthly cost has fallen, the value of £95/terminal/month is likely to be an overestimate, however, we have used it to illustrate the valuation methodology as the cost reduction is small relative to the difference in the WTP values. Also in our experience the added functionality (high speed data etc) is not of great interest to the PBR community, who prioritise reliable, instant voice communication.

The willingness to pay of an individual user depends upon the coverage they require relative to the amount of traffic they need to support. An organisation requiring low traffic across a large area will be more likely to see a mobile phone solution as a viable alternative (providing the coverage and functionality requirements can be met), whereas an organisation requiring high traffic over a small area is more likely to favour a PBR solution. This leads to a range of willingness to pay values for different organisations.

The demand curve is illustrated in Figure 6-1 for additional spectrum located at a specific frequency in an area where there is excess demand. The licensees are ranked according to terminal density within the exclusion area as a proxy for their willingness to pay for PBR. Also shown are the deployment costs per km^2 for the system.

Figure 6-1: Demand curve for PBR licensees



The marginal willingness to pay is given by the point on this curve corresponding to the amount of spectrum introduced to the PBR market and is the difference between the value of the PBR solution and the deployment costs. Note that commercial band managers may face additional spectrum management costs as the amount of exclusive spectrum (and hence number of users) increases,

[45] http://www.ofcom.org.uk/static/archive/ra/topics/economic/surveys/pmr.pdf

however we assume that these costs are small in comparison to the willingness to pay at the point where spectrum is limited.

6.2.2 How does value vary with base station deployment?

A PBR service operator has some system deployment options regarding the Effective Radiated Power (ERP) and the height of the transmitter antenna, which become embodied within the licence conditions. . Their choice is usually to minimise cost whilst still achieving the required operational coverage. Indeed, many licensees site the base station at their own premises to minimise cost and system complexity.

Higher ERP can be a result of higher transmitter power or higher antenna gain. Higher transmitter power is usually only of benefit for vehicular terminals since it helps match the coverage in both uplink and downlink directions. For low power hand portable terminals, higher power at the base station conveys little benefit since link budgets would be unbalanced and uplink path loss would be the limiting factor.

Higher antenna gains and higher sites can convey real benefits in coverage, depending on the site location. But both antenna installations and additional height cost more to implement. The use of high sited repeater stations requires a backhaul or reverse frequency link to the dispatch site, which will also incur additional cost. So the PBR community is characterised by a mix of PBR systems adopting various heights and ERPs.

Each deployment configuration results in a different interference range and sterilised area. The number of times the frequency can be reused in the UK can be estimated to a first approximation by dividing the area of the UK by the sterilised area of a typical assignment. At first glance, this might suggest that higher frequency spectrum with shorter range is more valuable than lower frequencies since more licensees would be able to share the same channel. However, considering this situation from the point of view of an hypothetical commercial band manager with access to cleared national frequencies leads to a different conclusion.

Consider a scenario where competing commercial band managers leased to user organisations geographic access to cleared spectrum which they had acquired in areas with excess demand.[46] If prices which all users were then willing to pay the band managers were the same, then band managers would select those requiring shorter range, since they allow greater re-use of each frequency and hence generate higher overall revenue for a given national bandwidth. Accordingly price competition would ensure that users paid charges that were commensurate with the relative opportunity costs they imposed on the band manager (i.e. relative areas sterilised). Therefore, band managers would structure their own leasing charges according to the deployment configuration and effectively gain an income per km^2 for leasing the spectrum that was independent of the deployment configuration.

6.2.3 How does value vary with frequency?

We need to consider variation in licensees' willingness to pay for spectrum in frequency in three respects.

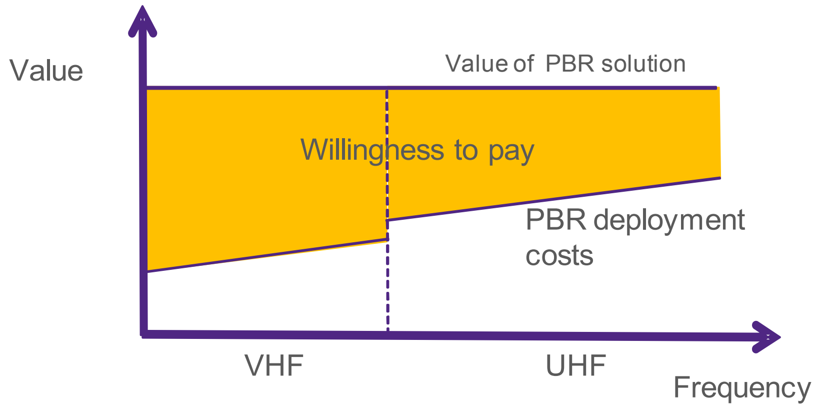
[46] Users might alternatively seek spectrum from Ofcom at the prevailing AIP rates.

- The variation within a frequency range where all frequencies are suitable for hand portable coverage (say 400 to 1000 MHz)
- The variation within a frequency range where all frequencies are suitable for vehicular coverage (say 50 MHz to 1000 MHz)
- The variation between UHF and VHF bands where there are significant differences in demand.

We have established that the hypothetical band manager's customers will choose an antenna system and height that matches the coverage desired whilst minimising cost. We can surmise that hand portable users are likely to prefer frequencies within the range 400 to 1000 MHz which will also have a bearing on the cost of implementing the system. In general, lower frequencies within the range will be more valuable for licensees therefore they should have a higher willingness to pay for them.

The situation for vehicular users is similar to hand portable users except that values will span both VHF and UHF since either frequency range is suitable to provide the service. The impact of these cost variations is shown in principle for a single vehicular licensee in Figure 6-2. This shows the marginal value of PBR outputs to the user as being constant with respect to frequency. This level could be the internal business benefit to the user or the cost of an alternative means of achieving similar communications, whichever is the lower.

Figure 6-2: Value of spectrum relative to alternative forms of delivery for vehicular users



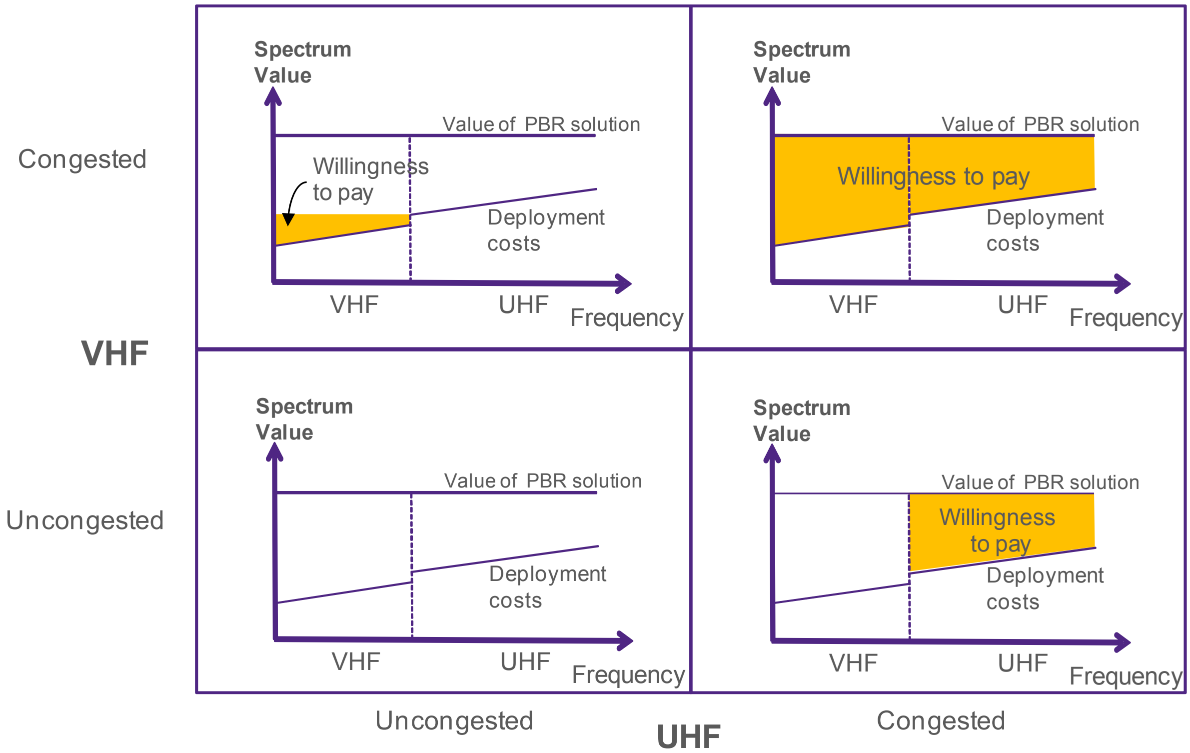
The PBR deployment costs are also shown in Figure 6-2, which can be seen to vary with frequency. Higher frequencies generally incur higher deployment costs. The difference between the internal value of the PBR solution and the user's deployment costs is the willingness to pay for access to primary supply or to the commercial band manager's spectrum, whichever is available.

If in a particular area there is no excess demand from users at the price at which primary supply is available to them (e.g. AIP), then additional frequencies are available from primary supply and the market clearing spectrum value available to the commercial band manager is essentially capped by the primary supply costs. If there is such excess demand then the user's willingness to pay sets a ceiling on the market clearing spectrum value to the commercial band manager at each frequency.

6.2.4 How does value vary with demand?

The willingness to pay for VHF and UHF bands may vary depending upon the relative levels of demand for these bands. A particular area may have one of four states of excess demand regarding the VHF and UHF bands depending upon the relative demand for the two bands at that location. The spectrum values in each case are strongly influenced by the fact that UHF is a substitute for VHF use, but VHF is not a substitute for UHF in the case of hand portable users. This is shown for the four cases in Figure 6-3.

Figure 6-3: Spectrum value where VHF and UHF may be have excess demand



Clearly where there is no excess demand for either VHF or UHF the spectrum value to a commercial band manager is capped by the relevant primary supply costs less its own spectrum management costs for both bands. Where both are still congested given prevailing primary supply costs then the clearing prices are set by the willingness to pay of users less spectrum management costs for each of the bands.

Where the UHF band is congested and VHF is not, the value of the UHF band is at the willingness to pay for that band less spectrum management costs because the VHF band is not a substitute for most UHF licensees. In contrast, where the VHF band is congested and the UHF band is not, the value of the VHF band is limited by the free availability of UHF substitute spectrum at prevailing primary supply costs. The value of VHF spectrum in this case equals the difference between deployment costs at the lowest freely available UHF spectrum less those at VHF, but capped at UHF spectrum primary supply costs less VHF spectrum management costs.

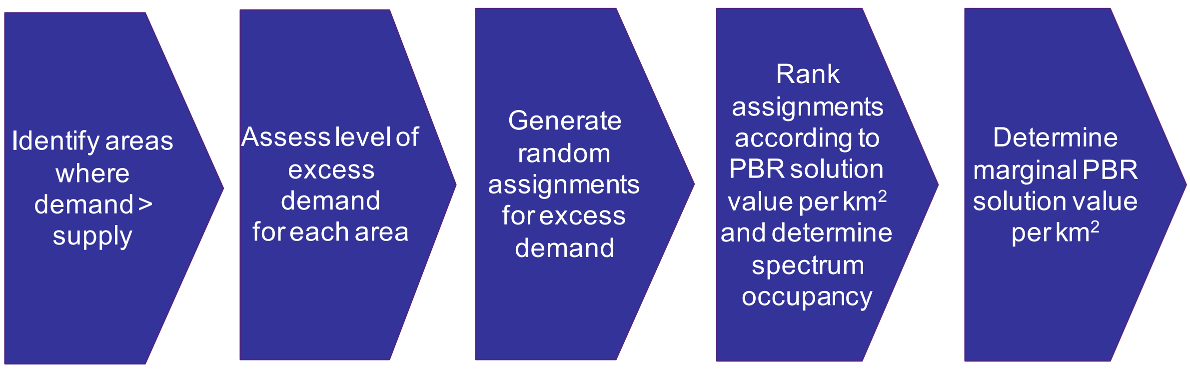
6.2.5 Income to a band manager

The foregoing shows how spectrum value to a commercial band manager for PBR use might vary at a specific location depending upon whether there is excess demand from users in the area. The value to a commercial band manager of a national licence can be considered from the point of view of the band manager wishing to optimise the commercial value of its national spectrum holdings. The total value of a spectrum band is given by the sum of the spectrum value attributed by its individual licensees. We expect that there is not excess demand for both bands right across the UK at prevailing primary supply prices given the categorisation of bands in the current fees order (Wireless Telegraphy (Licence Charges) Regulations 2005, Statutory Instrument 1378) where for certain products geographic areas were designated as heavily congested, congested or non-congested. To calculate total value to the hypothetical commercial band manager we need to isolate those areas where there is excess demand for VHF, UHF and both VHF and UHF.

6.3 Calculation of commercial value for PBR

The methodology for calculating the value of additional spectrum for PBR to a hypothetical commercial band manager is shown in Figure 6-4.

Figure 6-4: Approach to estimating PBR solution value



6.3.1 Identifying areas where spectrum demand exceeds supply

To implement the above approach to assessment a model was constructed to assess the potential commercial value of the VHF and UHF PBR bands. The analysis was based on Ofcom's database of PBR assignments, which included information on the location of base stations, the frequency of operation, RF and antenna details and the number of mobiles that are currently using each of the licensed frequencies.

There were approximately 9,500 VHF assignments in the database distributed over the VHF low, mid and high bands. There were also a number of band III assignments that were not included in the analysis because use of the band is constrained by the need to protect broadcast TV services that use the spectrum in neighbouring countries. The UHF assignments in the database comprised approximately 1,500 assignments distributed over UHF Bands 1 and 2. It should be noted that Band 1 in particular is constrained by the presence of other (Government) services in the band.

The effective occupancy of each assignment is a combination of its bandwidth and the area over which interference prevents its use. For each assignment an exclusion area was calculated based on the base station ERP, antenna gain and antenna height, using the Hata propagation model. These exclusion areas ranged from 530 km^2 to 31,460 km^2 (with an average of 23,800 km^2) for the VHF band, and 254 km^2 to 31,460 km^2 (with an average of 12,900 km^2) for the UHF band.

To understand how existing licensed demand varies by geography, the UK was divided into Ordnance Survey National Grid Squares of 100 x 100 km, with each grid square having an area of 10,000 km^2. This is commensurate with the average exclusion areas of VHF and UHF PBR assignments.

The spectrum demand in each area "A" arising from N_A PBR systems was calculated as the weighted sum of the individual assignments:

$$Demand_A(inMHz) = \frac{\sum_{i=1}^{N_A} Channels_i * ChannelBandwidth_i * ExclusionArea_i}{A} \qquad (1)$$

However there are three reasons why this might not reflect true demand:

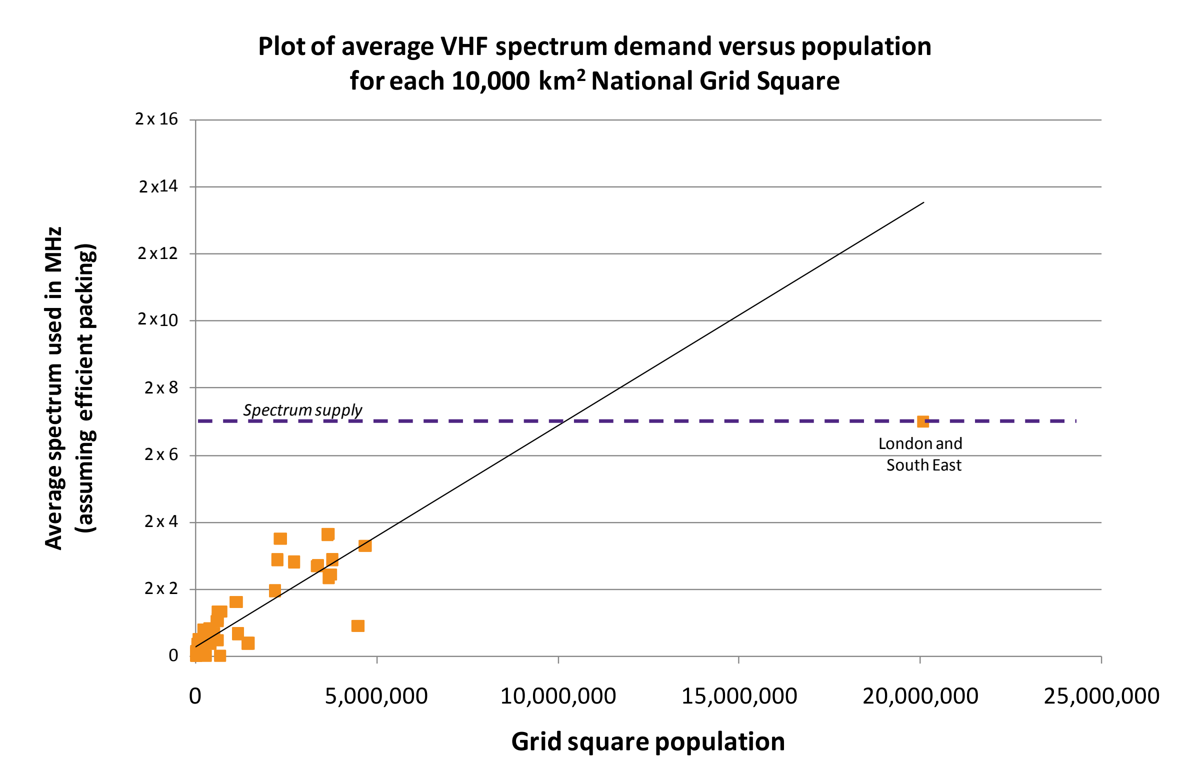
1. The formula calculates an average level of licensed demand within A (at prevailing primary supply prices) and true demand may vary within a given area. To deal with this we selected an area size that was sufficiently small to have relatively homogeneous demand
2. There may be practical difficulties in packing assignments having irregular areas and differing channel bandwidths into the spectrum. In addition, many assignments having few terminals may share the same channel within the same area. We dealt with these two effects by creating a "sharing factor" which reduced the calculated demand to spectrum supply in an area of known congestion (i.e. London and the South East).
3. Total demand may be limited by supply (where there is excess demand). In these cases, the assignment database will be an indicator of satisfied demand, not unmet demand. By establishing the correlation between population density and demand in non-congested areas, we may be able to extrapolate for areas of high excess demand using population density as a proxy.

Underlying the latter is the assumption that excess demand has the same distribution of willingness to pay as met demand. This is a reasonable assumption since Ofcom has traditionally assigned on a first-come first-served basis and therefore there has been little filtering of systems according to willingness to pay.

The above process allowed us to identify which of the areas have apparent excess demand for VHF or UHF spectrum at prevailing primary supply costs. The calculated VHF spectrum demand versus population[47] of the area is plotted for each grid square in Figure 6-5.

[47] Approximate population per grid square was obtained from Center for International Earth Science Information Network (CIESIN), Columbia University;and Centro Internacional de Agricultura Tropical (CIAT), 2005. Gridded Population of the World (GPW), Version 3. Palisades, NY: CIESIN, Columbia University.
Available at http://sedac.ciesin.columbia.edu/gpw.

Figure 6-5: Plot of effective VHF spectrum occupancy versus population for each grid square

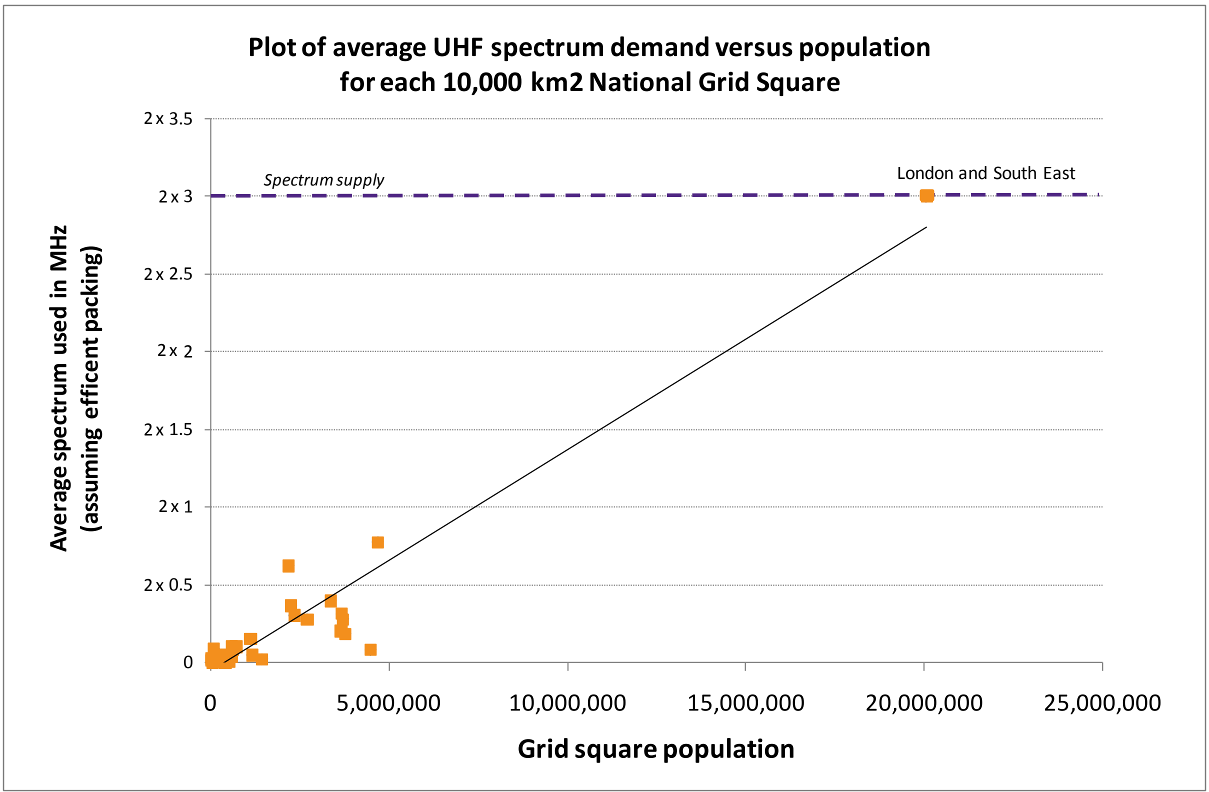


Source: Plum analysis

It can be seen from Figure 6-5 that the majority of Grid Squares have spectrum demand far less than the total 2 x 7 MHz available in the VHF low, mid and high bands. The exception is the grid square encompassing Greater London, Kent, Surrey and East Sussex which has licensed spectrum demand of 2 x 7 MHz equal to the available capacity. The trend line through the points excluding the London grid square shows a degree of correlation between population and spectrum demand. The spectrum demand for London is well below this trend line which suggests that very significant excess demand for licensed spectrum in this area at prevailing primary supply prices.

Performing similar analysis for the UHF spectrum assignments the calculated spectrum demand versus population is plotted in Figure 6-6 for each grid square.

Figure 6-6: Plot of effective UHF spectrum occupancy versus population for each grid square



Source: Plum analysis

It can be seen from Figure 6-6 that spectrum occupancy in London and the South East is reasonably consistent with the trend line. Although we understand based on the categorisation of areas in the current fees order that the UHF PBR bands are congested in London, this chart suggests that there is as yet little excess UHF spectrum demand at prevailing primary supply prices (i.e. the prevailing AIP levels).

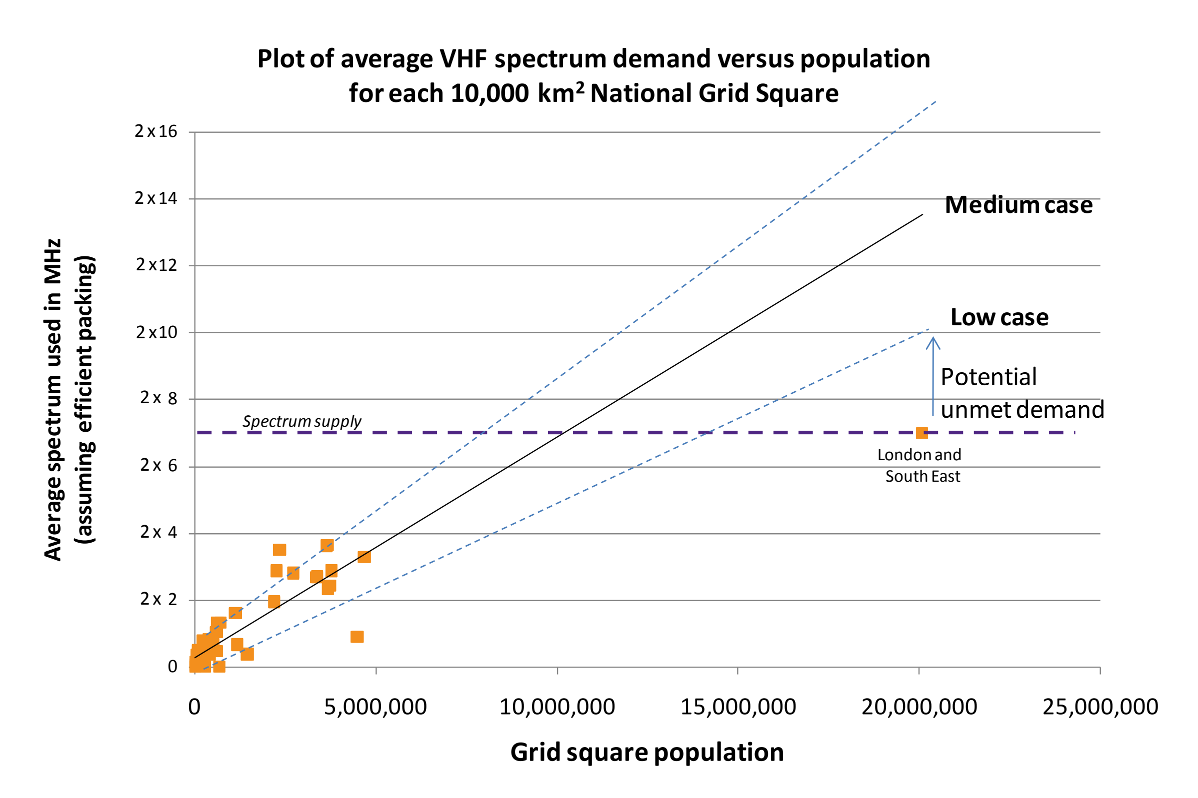
6.3.2 Determining value in congested area

We have established that only one grid square is congested (London and the South East) and that it is congested in both VHF and UHF bands.

We have also established that there is substantial excess (unmet) demand for VHF assignments.

By extrapolating the potential bounds of the trend line we estimated a low and medium case for the unmet demand. This is illustrated in Figure 6-7.

Figure 6-7: Effective VHF spectrum demand taking account of packing efficiency



Source: Plum analysis

From this we concluded that the unmet demand is at a similar level to the existing VHF assignments for the medium case and 40% of existing assignments for the low case. To analyse the medium case we assumed that the unmet demand would have similar characteristics to the existing assignments. For the low case we choose at random 40% of the existing assignments to represent the unmet assignments.

6.3.3 Calculate PBR value / km^2 in each of the areas

This stage calculates the incremental commercial value per km^2 of harmonised and non-harmonised spectrum in the identified area of existing excess demand.[48] We have identified that the grid square TQ encompassing London is this area for the VHF band at prevailing AIP price levels for primary supply, therefore the following analysis is for that square only.

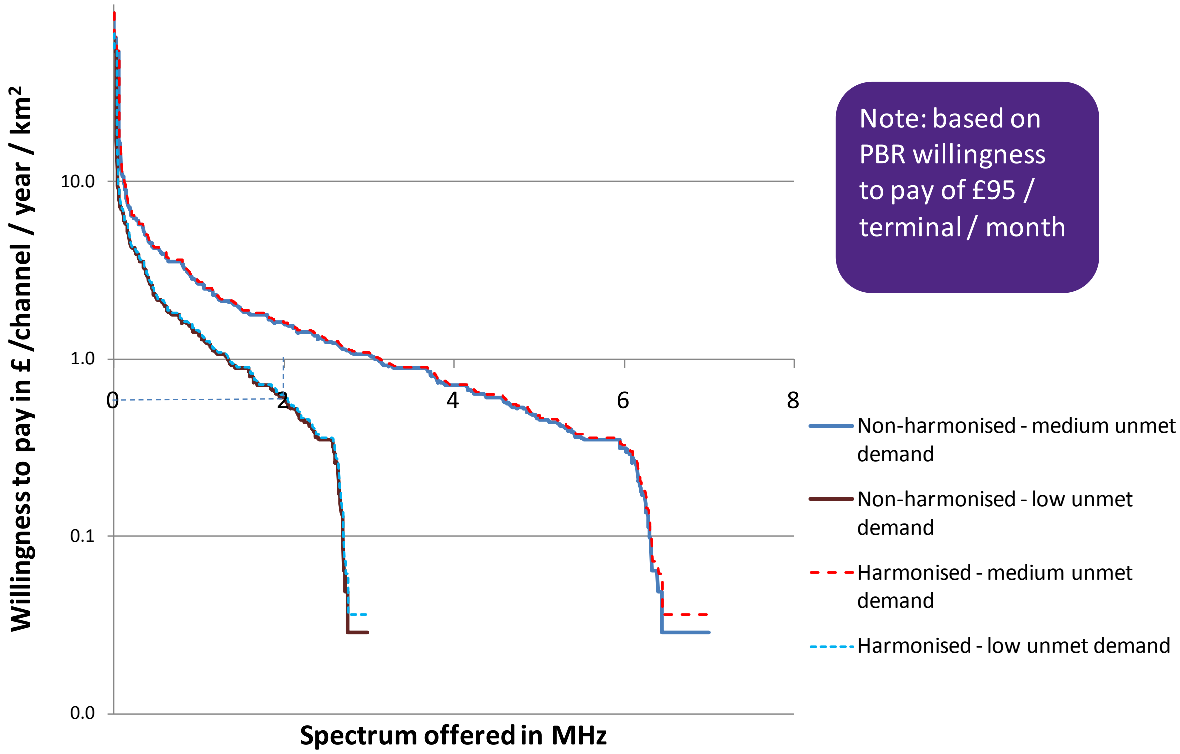
To calculate the willingness to pay for harmonised spectrum for each unmet assignment, we multiplied the number of terminals using each assignment by an illustrative assumed marginal willingness to pay value of £95 / terminal / month reflecting historic research conducted by the Radiocommunications Agency as discussed in section 6.2.1. For non-harmonised spectrum, weaker scale economies can

[48] Non-harmonised spectrum in this context is a substantial amount of spectrum made available by a band manager which has potential to be used by a sufficiently large number of terminals for equipment manufacturers to include it as an option within their product ranges. We have used 2 x 2 MHz of additional spectrum as the basis of our example calculations.

be expected for equipment supply and therefore the estimated incremental cost of terminals and transmission equipment are subtracted from the above marginal willingness to pay.

The assignments were ranked by overall value and the demand contributed by each system was calculated according to equation (1). By accumulating the demands we find the point at which the additional spectrum offered is exceeded. The result is shown in Figure 6-8 for both harmonised and non-harmonised spectrum.

Figure 6-8: PBR willingness to pay per km^2 as a function of the amount of VHF spectrum offered



Source: Plum analysis

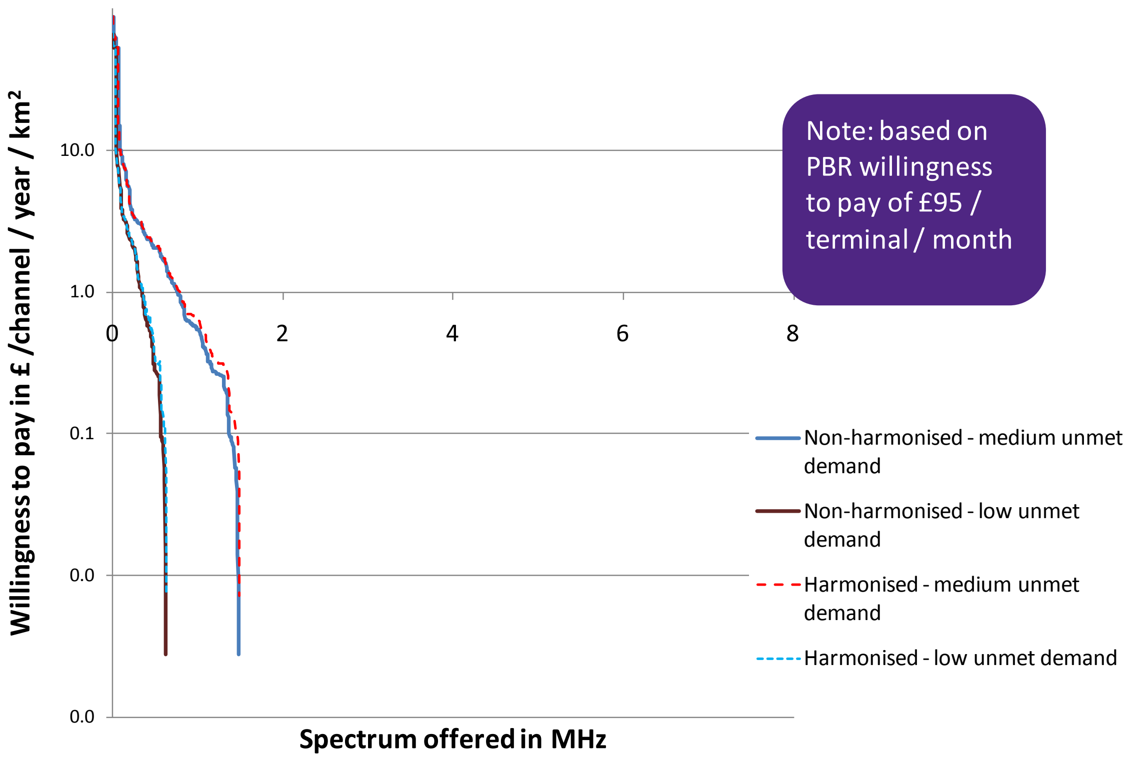
It can be seen from Figure 6-8, that there is little difference between the willingness to pay for harmonised and non-harmonised spectrum. This is because the incremental equipment costs of using non-harmonised spectrum are small compared to willingness to pay when amortised over a typical 10 year equipment lifetime. Using the results shown in Figure 6-8, 2 x 2 MHz of harmonised spectrum would be valued at £0.60 per channel / year / km^2 (where a channel is 2 x 12.5 kHz) for the low unmet demand case. Assuming a discount rate of 10% and a linear increase in take-up over a 10 year period, this equates to an absolute buyer's valuation of £2.8M for an additional 2 x 2 MHz block at VHF across the entire 10,000 km^2 TQ grid square. However, it should be noted that spectrum management costs (administration, planning and spectrum management charges by Ofcom) would need to be subtracted from this figure to obtain the maximum clearing price in a spectrum trade.

If we consider the potential sale of VHF spectrum currently used for PBR for an alternative use, then the value to the current spectrum holder would be around £6M for 2x2 MHz assuming the same demand curve but that all users are present at the start of the ten year period. Any transaction costs associated with moving existing users to another band or service would need to be added to this amount to get an estimate of the lower bound on the price that the existing owner would be prepared to accept.

Similar analysis can be undertaken for UHF spectrum. Although excess demand for UHF spectrum was not implied by the assignment data, we know anecdotally that making new assignments in London in the UHF band is difficult. Since the excess demand for VHF can in theory utilise the UHF albeit with more base station sites, then the same estimated excess demand can be used to value the UHF band.

Using a similar process as for the VHF band but subtracting the additional base station costs provides a valuation for the UHF band shown in Figure 6-9 for both harmonised and non-harmonised spectrum. It can be seen that the value is substantially affected by the difference in frequency. This is because additional base stations are required and these incur establishment costs and require ongoing maintenance. In addition, for potential licensees having few users, the extra deployment costs can outweigh the overall willingness to pay for PBR spectrum. For these potential licensees the UHF is not a substitute for VHF spectrum.

Figure 6-9: PBR willingness to pay per km^2 as a function of the amount of UHF spectrum offered



Source: Plum analysis

Like the VHF band analysis, there is little difference between the valuations for harmonised and non-harmonised spectrum. We can also see that under the low and medium demand scenarios considered, there is insufficient excess demand to occupy 2 x 2 MHz of UHF spectrum.

Using the results shown in Figure 6-9, 2 x 0.5 MHz of harmonised spectrum would be valued at £0.30 per channel / year / km^2 (where a channel is 2 x 12.5 kHz) for the low unmet demand case. Assuming a discount rate of 10% and a linear increase in take-up over a 10 year period, this equates to an absolute buyer's valuation of £0.35M for an additional 2 x 0.5 MHz block at UHF across the entire 10,000 km^2 TQ grid square.

If we consider the potential sale of UHF spectrum currently used for PBR for an alternative use, then the value to the current spectrum holder would be around £0.74M for 2x0.5 MHz assuming the same demand curve but that all users are present at the start of the ten year period. Any transaction costs associated with moving to another band or service would need to be added to this amount to get an estimate of the lower bound on the price that the existing owner should be prepared to accept.

6.4 Comparison with other values

The AIP value that is already levied by Ofcom for primary supply in the most popular frequency bands in a high population area is £1,185 per 2 x 12.5 kHz channel per 2500 km^2 area, equivalent to £0.47 per km^2 for both VHF and UHF spectrum. For a full band in London and the Southeast and assuming payments over a 10 year period this is equivalent to an NPV of £3.3M for 2x2 MHz or £0.8M for 2x0.5 MHz. This implicitly includes payment for Ofcom's spectrum management costs as well as the opportunity cost of unmanaged spectrum.

We note this value is around half of that obtained above for 2x2 MHz of existing PBR spectrum in the VHF band, and slightly higher than that obtained for 2x0.5 MHz in the UHF band. In general, we would expect AIP values to be lower than calculated spectrum values but we consider that the values compare well given the uncertainty concerning PBR willingness to pay (which may have increased since the Radiocommunications Agency study in 2000). Although the existing primary supply prices include spectrum management costs, so too do the estimates of value developed above. The actual clearing price in a trade could be expected to be lower once spectrum management costs are taken into account.

In October 2006, Ofcom held the first (and so far only) auction for unmanaged PBR spectrum, comprising 2x2 MHz in the 410 – 430 MHz band, available nationally but with some constraints due to the presence of MoD services in the North of England. The price paid by the successful bidder (Arqiva) for an indefinite term[49] licence was £1.5 million for 2x2 MHz. This is around four times the incremental commercial value estimated above for 10 years' access to 2x0.5 MHz of UHF spectrum (ignoring spectrum management costs). Although our analysis suggests that the value would be even lower if more spectrum than 2x0.5 MHz is made available, other factors may account for the perceived higher value of this spectrum as follows:

- The indefinite term of a licence increases the returns that can be expected compared to a 10 year period
- Buyers may have a more optimistic view of market growth and spectrum utilisation than the static view of PBR users illustrated here
- Clearing prices can include option values where flexibility in spectrum use is desirable (as noted in Section 2)

[49] The licence has an indefinite duration but can be terminated at any time after an initial term of 15 years by Ofcom for spectrum management reasons with not less than five years' notice.

We note that future releases of MOD and other public sector spectrum may involve significant sharing which will have variable impacts on commercial value and hence necessitate a band by band approach to commercial valuation and the impact of enduring public sector constraints.

6.5 Conclusions

In summary, we have presented a methodology by which the commercial value of spectrum for PBR may be understood from the perspective of an hypothetical commercial band manager and estimated using existing assignment data. Spectrum for PBR has project-based value only in areas of likely excess demand. Analysis of the existing assignment data showed that within the UK only the greater London area is currently congested for PBR; here it is congested in both VHF and UHF bands and the data implies considerable excess demand for VHF channels. The project based value of additional spectrum is given by what a commercial band manager would be able to charge users per km^2 based on the number of channels and exclusion area they occupy, less the spectrum management costs of making this spectrum available to users. Assuming that the excess demand at prevailing primary supply prices exceeds the capacity of the additional spectrum and users with the highest willingness to pay gain preferential access to the new band, the maximum that a commercial band manager could charge for the spectrum is given by the marginal willingness to pay of PBR users less any additional costs they face (such as higher equipment costs to use non-harmonised spectrum or increased deployment costs arising from the use of higher frequencies). The value of additional spectrum per MHz was shown to decline with the quantity of spectrum as the marginal willingness to pay also declines.

Using a baseline 2 x 2 MHz of additional “new” spectrum to illustrate the value, we estimated the commercial value of additional VHF spectrum to be £0.60 / MHz per km^2 in Greater London. The use of harmonised or non-harmonised spectrum did not make a significant difference to this value. This translates to an absolute value of £2.8M for the 2 x 2 MHz block. The value of a UHF block was substantially lower since users would incur higher deployment costs. It is estimated at £0.30 / MHz per km^2 or £0.35M for a 2 x 0.5 MHz block. We found existing assumed levels of excess demand at UHF can all be met by an additional 2x0.5MHz of spectrum. We note that this means it does not make sense to gross the value up to a 2x2MHz block, as spectrum beyond 2x0.5 MHz is likely to have a much lower value, even when future demand growth is taken into consideration in the context of longer term licence valuations.

The values can be compared with the auction price of unmanaged spectrum and with Ofcom’s existing primary supply prices for managed spectrum. Current AIP rates for the PBR bands are broadly comparable although there is no distinction between charges at VHF and UHF. The one market benchmark for the auction of 2 x 2 MHz in the UHF spectrum band was £1.5M which is higher than our estimated value of UHF spectrum, but the benchmark price was for a longer duration and may include option values and be based on more optimistic PBR growth assumptions.

The methodology is made possible by the large numbers of assignments in the VHF and UHF spectrum bands. However, the methodology could be improved by

- Updating the estimate of willingness to pay for PBR. The values used in our analysis were derived in 2000 and are likely to be out of date

- Likely levels of future excess demand are calculated based on the existing profile of demand. A better understanding of how the extent and profile of demand may be changing would be beneficial
- Greater scrutiny of the precise assignments, to better understand areas excluded and packing densities, would enhance the accuracy of the method.

In contrast with other applications such as cellular mobile and broadcasting, there is a large degree of homogeneity between the deployments, equipment used and economic benefits obtained from the use of the spectrum. The large number of individual users enables a more statistical approach to be taken.

7 Broadcasting Networks

7.1 Introduction

Broadcast networks aim to deliver the same content to as many people as possible and their costs are therefore mainly coverage rather than capacity driven. Capacity is relevant to the extent that delivering more content channels requires more spectrum capacity (all other things being equal), but this capacity is not related to audience size for a given content channel. Hence traditionally national terrestrial broadcasters have deployed networks with a relatively small number of very high power transmitters to serve a target (typically large) population at low cost. This is unlike the situation with mobile networks where capacity requirements are determined by the number of users in a given area, hence the network models for broadcasting and mobile services are very different (e.g. 80 % of the UK population can be served from 80 broadcast TV transmitters, whereas many thousands of sites would be required to serve a similar number of cellular subscribers).

The modelling described in the fixed point to point and single site deployment chapters was focussed on considering the value of an incremental block of spectrum to a hypothetical commercial spectrum manager, and in both cases the modelled value was driven by the assumed infrastructure and receiver cost differences between different frequency bands. For cellular mobile services we calculated the value of incremental spectrum to an operator buying spectrum where the valuation was based on the net infrastructure and receiver cost savings that could be made as a result of acquiring additional spectrum.

In this chapter we first consider the feasibility of valuing broadcasting spectrum using a similar approach that focuses initially on spectrum/infrastructure and receiver cost trade-offs, assuming output remains constant. This approach involves relaxing constraints on spectrum use and assuming that spectrum licences in bands used for broadcasting are tradable (which is not the case in practice). As such it removes the need to make assumptions about the content, funding and coverage of the broadcast service. We also consider an alternative approach to spectrum valuation based on the business case for incremental spectrum/transmission capacity.

7.2 Infrastructure/spectrum trade-offs

7.2.1 Television

If a DTT multiplex operator had access to incremental spectrum frequency it could in principle use fewer transmission sites. However in practice broadcasting networks have generally been designed to achieve a given level of coverage with relatively few transmission sites (i.e. to maximise coverage per transmitter) taking account of environmental and spectrum planning constraints. Trade-offs in the other direction, in which more sites with lower powered transmissions and less spectrum (e.g. in a Single Frequency Network (SFN)) are used, are more likely to be feasible. The implied value of spectrum would be the minimum amount a seller would accept from a buyer to reduce its spectrum use while maintaining a profit-maximising level of coverage, which is assumed in this analysis to be constant.[50]

For example the current approach used for DTT involves the use of traditional high power transmitters using (for each national DTT multiplex) six 8 MHz frequency channels. Possible alternatives in which fewer 8 MHz frequency channels are used might involve

- **More sites and an SFN:** Replace the 80 high power transmission sites with around 1,000 lower powered sites, which would allow the possibility of operating the network as a single rather than a multiple frequency network. This assumes the multiplex is not used to provide regional services, the 1100 or so relay sites continue to operate as at present and the environmental impacts of an additional 1,000 low power sites can be ignored.
- **Use an alternative technology to deliver an SFN**: the existing 1154 high power and relay transmission sites but with a different transmission technology i.e. DVB-T2 (which is being deployed on one existing multiplex[51]) which allows a sufficient guard interval for operation as an SFN rather than an MFN
- **Use alternative platforms**, such as cable, fibre or satellite transmission in selected areas. We consider the specific case of satellite transmission only.

Changing the network configuration, technology or transmission platform has an impact on one or more of the coverage, the possible nature of the broadcast service and /or the ability of households to receive the service without changes to reception equipment (e.g. set top boxes). The impacts are summarised in Table 7-1, together with some estimates of the costs of releasing UHF spectrum to a given multiplex licensee.

The calculations given in Table 7-1 assume that coverage for a commercial multiplex (i.e. 80% population coverage) is maintained in all options. If this constraint is relaxed then the costs of the spectrum would be much lower in the first case where the costs incurred are associated with maintaining coverage to rural areas. The second case involves re-equipping households that do not voluntarily purchase set top boxes to receive DVB-T2 transmissions. It is difficult to judge the extent of take-up but it would clearly be more attractive if more than one commercial multiplex moved to this transmission mode. In the third case of moving to satellite, we doubt that it would be financially worthwhile for a single multiplex to make this move given the substantial costs of re-equipping households to receive satellite transmissions. Rather all terrestrial broadcasting would need to move to the satellite platform to justify these costs.

We observe that the costs/MHz shown in the right hand column of Table 7-1 can be compared with the opportunity cost estimate for UHF broadcasting spectrum obtained by Indepen and Aegis (2006). This value was derived from traded prices for multiplex capacity at the time, and amounted to annual value of £0.5m/MHz. Converting this to a net present value over 15 years at a 10% discount rate gives a value of around £4m/MHz. If this is still a fair indication of the market value of the UHF spectrum for broadcasting then our analysis suggests that a single multiplex operator would not undertake the actions to release spectrum described in Table 7-1 but that co-ordinated action by several multiplex operators could be worthwhile.

[50] By assuming coverage is maintained we ignore the possibility that net revenues lost by reducing coverage may be less than the costs of additional transmission sites.

[51] This multiplex will carry HD services using MPEG-4 and DVB-T2 technology. Services are expected to be launched in late 2009 and will provide coverage to 50% of the population within the next 12 months.

Table 7-1: Costs of using less UHF spectrum for a given multiplex

Option	Spectrum saving	Additional transmission costs	Consumer impacts	Cost / MHz
More sites and a SFN	Up to five 8 MHz channels i.e. 40 MHz per multiplex	Net cost of transmission from 1000 low powered sites instead of 80 high powered transmitter sites We estimate operating costs will be similar i.e. no net cost difference once sites established.	Some loss of coverage in rural areas that receive an umbrella service from main transmitters. Provision of satellite dishes to rural users affected could address loss of coverage (to say 5% of households). Implied cost would be around £300m.[52]	£7.5m/ MHz
Use DVB-T2 and an SFN	Up to five 8 MHz channels i.e. 40 MHz per multiplex	No material difference in costs	Households need new set top boxes to receive the service. To equip all terrestrial TVs covered by a commercial multiplex[53] with a new set top box would cost around £1.7bn. By the end of 2010 50% of the UK population will be able to receive HD PSB services if they purchase a DVB-T2 box. It is possible therefore that much lower expenditures would be required to maintain reception. Assuming most of the 50% covered opt for a DVB-T2 STB then £1bn sets an upper bound on costs.	£0-25m/MHz
Use satellite instead of terrestrial transmission	Up to six 8 MHz channels i.e. 48 MHz per multiplex	None. Any significant services will already be broadcast by satellite.	Satellite dishes and STB for around 16m hholds Also reception of multiple sets in some satellite homes would need to be enabled Costs of £3-4bn (given Freesat costs)[54] excluding costs of enabling additional sets in satellite hhlds	£60-80m/MHz

Source: Plum analysis

[52] This is based on the costs of enabling Freesat reception on all TV sets in the house using a basic set top box and based on installation costs given at www.freesat.co.uk

[53] It is assumed that the commercial multiplex operator has 80% population coverage.

[54] http://www.freesat.co.uk/index.php?page=help.Question&id=43

7.2.2 Radio

Similar issues arise in the case of broadcast radio services. In the case of analogue radio, it is difficult for licensees to change their transmission parameters (e.g. to use a lower power, or a less elevated site) so that they reduce the level of exported interference. This is because there needs to be a mechanism by which the band may be re-planned after any such modification, to exploit the lower interference levels. Indepen et al (2005) provide the following example which shows that considerable replanning would be required to release FM radio spectrum.

Consider the case of the local radio services at Guildford and Southend, which may be said to be ‘blocking’ a channel in London. This is, to a large extent, correct, but the complexity of the situation becomes clear when the detail is examined.

- The Guildford transmitter operates on 96.3 MHz, that at Southend on 96.4 MHz. If neither of these transmitters were used, it would be possible to make use of one of the two channels to cover the London area.
- While these two stations are the dominant interferers, there is also a station at St. Albans on 96.6 MHz and in North-West Kent on 96.7 MHz. Both of these stations would suffer unacceptable interference if a new London service were to be introduced. They would also be likely to generate significant interference within parts of the London service area due to their greater proximity of the services.
- A further complication is that it is not only by virtue of outgoing interference power that an existing service constrains the use of a channel in a given area, but by also by requiring protection from interference. The interference to, and from, continental stations might also need to be considered.
- If Guildford (for example) were to sell its spectrum (i.e. close) the Southend transmissions would continue to block a London service. Co-operation between Southend and Guildford is required to offer any possibility of a new London station covering Guildford, London and Southend.
- So, while it might appear that Guildford and Southend could co-operate to close the existing local services, and to provide a joint Guildford-London-Southend service, this would require additional power to be radiated that would be likely to cause interference to services further afield. And hence other stations would need to be replanned.

Radio station operators would need to weigh the disruption caused (e.g. by frequency and coverage area changes) against the gains in spectrum capacity that would be likely to arise.

It is perhaps more practical to consider how additional DAB channels might be planned to reduce spectrum requirements by deploying more transmission infrastructure. Indepen et al (2005) considered this possibility. If an existing network comprising three transmitters (typical of current regional multiplexes) were to be replaced with one comprising eight transmitters, this might typically result in a reduction in the sterilised area of around 20% (in practice, the reduction will vary according to the local topography and availability of transmitter sites, but a typical value of 20% would appear reasonable). Working this through for a particular frequency channel Indepen et al estimated a cost/MHz of £3.6m.

7.2.3 Summary

In summary, our analysis suggests that there would be a need for co-ordinated action by DTT multiplex licensees and analogue radio broadcasters to release spectrum in a cost-effective manner. The possibility that such action may be difficult to achieve in practice suggests that the infrastructure/spectrum trade-off approach may not be appropriate for valuing spectrum to a single buyer or seller. We next consider valuation based on business case analysis.

7.3 Business case analysis

If terrestrial broadcasting was like any other commercial business we would estimate the value of its use of spectrum by considering whether the spectrum under consideration was used to enhance the service offering (e.g. extend coverage or launch new services) or reduce costs. Depending on which situation applies the appropriate modelling would be undertaken. In practice, however, many of the commercial choices facing broadcasters are constrained by regulation. In particular broadcasters are regulated (in varying degrees) through controls on the content they may offer, the ways in which they can raise revenues and the coverage of their services where the latter is platform specific i.e. is specific to the terrestrial platform (for their analogue services and the simulcast digital services) so that cable and satellite delivery cannot be regarded as feasible substitutes. In addition technical transmission parameters, such as the compression standard, the modulation etc., for analogue and digital TV broadcasters are determined by regulation. A similar situation applies to analogue radio broadcasters, though content controls are not as specific as for TV.

We consider the possible business case analysis and market data for each of TV and radio in the sub-sections below.

7.3.1 Television

Licences for spectrum for terrestrial TV broadcasts do not attract AIP. The spectrum is currently regarded as a resource that partly pays for uneconomic programme and coverage obligations.[55] Although Ofcom has proposed to begin charging AIP based licence fees for this spectrum from 2014.

To value incremental commercial spectrum used by TV (for non-PSB purposes) we could consider the expected profitability of additional channels that might use commercial multiplex capacity. The profitability of a television broadcaster depends importantly on the attractiveness of the content it offers. This determines the size and nature of the audience it can attract for a given coverage and so the revenues it earns either from subscriptions, advertising or both. In a multi-platform market, such as the UK all the most popular channels are distributed on all the main transmission platforms, as transmission costs comprise a relatively small proportion of the total channel costs (see Table 7-2).

[55] This is discussed at some length in Ofcom's PSB reviews. http://www.ofcom.org.uk/tv/psb_review/

Table 7-2: Cost structure for some UK TV broadcasters

	BBC - TV[56]	Channel 4[57]	ITV[58]	BSkyB[59]
Programming/ content costs	78%	70%	68%	38%
Distribution costs incl. transmission	4%	9%	5%	15%
Other costs	18%	21%	27%	47%

Source: Broadcasters annual reports, Plum analysis

Incremental commercial uses of radio spectrum to provide TV services are less likely to be tightly regulated than the incumbent PSB services, and so the commercial value of spectrum in this application should be simpler to estimate. Possible ways of estimating this value include

- Estimating the value from bottom up modelling of business cases for TV services
- Inferring the value from market data i.e. from the sale of UHF spectrum or multiplex capacity sales

Estimates of the profitability of an advertiser financed service broadcasting to a number of UK cities have been produced by Oliver &Ohlbaum (2009) for Ofcom. These estimates are for a single broadcasting TV channel that has programming networked across 15 cities for 6 hours a day and 5 hours of local programming per day in each city. The results rest importantly on the assumption that the channel achieves an average 1.5% audience share and so achieves a reasonable advertising rate. (By contrast Sky 1 achieves a 1.4% share and BBC3 a 1.2% share[60] (with a budget of £125m)). The estimated profitability of the channel in year 3 of its operation is shown in Table 7-3. As can be seen the channel is very profitable when serving 5 cities and the profitability declines as more cities are added. Estimated profitability could however be increased if less local and more networked content (with more fixed costs) was assumed to be transmitted. The issue for this study is how much of this operating profit might be regarded as commercial surplus that would be affected by marginal (frequency and/or geographic) changes in the availability of spectrum suitable for DTT transmissions. This depends on the riskiness of the business (and so the share of the operating profit that constitutes a normal return to capital).

[56] http://downloads.bbc.co.uk/annualreport/pdf/bbc_ara_2008_exec.pdf

[57] http://www.channel4.com/about4/annualreport.html/annualreports-2007/index.html

[58] http://2008.itv.ar.ry.com/?id=26164

[59] For the half year ended Dec 2008 http://corporate.sky.com/documents/pdf/1ffb247d89b6490c9cd3dc7a4f24f4eb/interim_man_report_09

[60] http://www.barb.co.uk/report/weeklyViewingSummary

Table 7-3: Estimated Revenues, costs and operating profits for year 3 of a multi-city TV station

	Top 5 cities (8.4 m hhlds)	Top 10 cities (12.2 m hhlds)	Top 15 cities (14.2 m hhlds)
Revenues (£m)	48	64	76
Programme costs (£m)	13.5	27	41.5
Fixed costs (£m)	12.5	25	37.5
Operating profit (£m)	22	12	-3

Source: "The sustainability of local commercial TV", Oliver and Ohlbaum, January 2009
http://www.ofcom.org.uk/consult/condocs/psb2_phase2/statement/annex4.pdf

The orders of magnitude of the estimated surplus suggest that competitive payments for spectrum access in the 5 main cities could run to millions of pounds even after normal returns to capital have been paid. For example even with a 20% margin (on revenues), the remaining surplus could amount to around £10m p.a. These values are comparable to the historic prices paid for a single channel on a national multiplex of £5-10m p.a. This capacity was auctioned by the multiplex operator through a sealed tender process in 2005 and implied an annual spectrum value of around £0.5m/MHz (equivalent to around £4m over a 15 year licence period). The market has of course changed considerably since then - in particular the outlook for economic growth and advertising revenues is much more depressed - and so it is doubtful whether such prices would be realised today.

Ofcom's recent auctions of 2 UHF 8 MHz lots for single-city services (including DTT multiplexes) – one covering Cardiff and one covering Manchester – each attracted only a single bidder. The frequencies each sold for the reserve price of £10,000, implying a very low value for the spectrum. This could be the combined result of the relatively small size of the markets, the limited appeal of local programming additional to that already provided by local and national broadcasters, the upcoming awards of spectrum offering more valuable bandwidths and coverage, and the economic situation.

In summary business case analysis suggests that the key drivers of value are the overall economic situation, size of market (which affects audiences and so revenues), programme costs, the competitive situation and the nature of content regulation. Most of these variables are highly specific to the channel line-up on the multiplex.

7.3.2 Sound broadcast networks

Radio stations are funded by advertising revenues and their cost structure is as shown in Table 7-4. The first three cost items are directly variable whereas the other costs are more fixed. These more fixed costs comprise around 70% of total costs and so profitability depends on getting a large audience and will show considerable variability in response to quite small fluctuations in advertising revenues.

Table 7-4: Ofcom data on the breakdown of radio station costs[61]

Cost item	% costs	Comment
Sales commission	13%	Variable with revenue
Royalties	15%	Variable with revenue
Other direct costs	2%	Costs of commercial production and sponsorship
Staff (non programming)	25%	
Marketing	5%	
Transmission	5%	Fixed in long term contracts
Programming	20%	
Premises	10%	
Administration	5%	

Source: The Future of Radio, Ofcom, 2006

The relationship between station profitability and size of the potential audience is shown in Figure 7-1 for 2006. As can be seen many small stations were unprofitable, and only the largest local stations made sizeable profits. There are now likely to be even more stations that are unprofitable because of the downturn in advertising revenues (these have fallen by 4% since 2006 and are expected to decline a further 8% in 2009).[62]

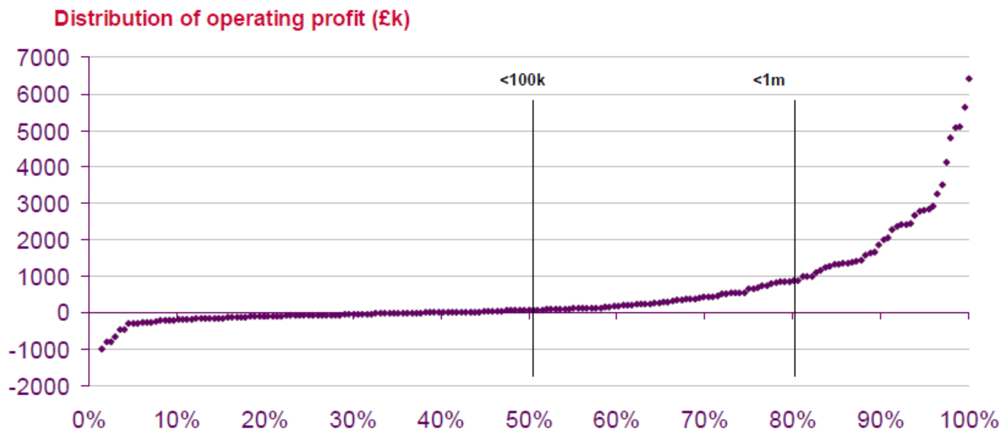
It therefore appears that the current industry structure is supported by cross subsidy from large to small stations. And low cost spectrum is used to help support the current system of regulation of commercial stations (which affects the population served and the content distributed), the roll-out of unprofitable DAB services and the provision of BBC radio services.

[61] http://www.ofcom.org.uk/consult/condocs/radio_future/radio_future.pdf

[62] http://www.rab.co.uk/rab2006/showContent.aspx?id=355

Figure 7-1: Station profits and size, 2006

Figure 15: The distribution of operating profit at local commercial stations



Source: Ofcom licensees

National commercial radio stations bid for their licences and their annual payments give an indicator of the "surplus" earned from the spectrum. Indepen et al (2005) report that in 2004 licence payments were as follows

- For Classic FM, the payment totalled £3.9m for access to 2.2MHz of spectrum on a national basis, implying a value of £1.8 m/MHz
- For Talksport and Virgin on AM, average payments were £1.6m each and each service uses two 9 kHz channels implying an average value of about £0.09m/kHz.[63]

These licences expire in 2011 and will be tendered in advance of that date. The value bid for the licences will in effect be a measure of the value of the spectrum, given the content and other controls contained in licences. This is all very uncertain at present as the nature of future regulation for analogue and digital radio is currently under review.[64]

7.4 Using non-harmonised frequencies

To utilise non-harmonised spectrum for fixed television broadcasting, there are two main requirements to make a business proposition feasible from a technical point of view.

- Each subscriber would need to have a set-top box, and possibly a new aerial, that is able to utilise the new frequencies. For a local network the lack of scale economies would result in very expensive set top boxes assuming the spectrum is not used elsewhere.[65]
- Transmitters may need to be co-located with existing DTT transmitters so that households are able to receive the new channels without requiring aerial re-alignment or a second aerial. However if all households needed new aerials because of the change in frequency range then co-siting of transmitters would not be necessary.

[63] As very little spectrum is available in the AM band it is not appropriate to convert this to a value/MHz.

[64] See for example proposals to significantly change the regulation of radio given in http://www.ofcom.org.uk/radio/ifi/radio_digitalbritain/

[65] The main exception here is band III which is used in some other countries for TV broadcasting.

If additional DTT capacity is provided from existing broadcasting sites, the main engineering consideration will be the power of the transmitter required to achieve a particular coverage at a different frequency. There will be an upper limit to the frequency that can be considered due to the maximum power of a transmitter that can be manufactured at any given frequency.

For broadcasting systems, as the frequency used rises above the UHF band, antenna performance improves, so little if any extra power is required from the main transmitter sites. However, geography dictates that coverage will be far less even – therefore requiring more repeaters.. Implementing additional repeaters not only incurs the direct cost of the sites, it would also require the installation of a second aerial at the customer's premises so that the original aerial can be directed at the sites used by other broadcasters. This measure would be costly and also unattractive from a marketing perspective. Therefore, we can assume that the business proposition dictates that repeaters cannot be used extensively so that in practice additional spectrum of value to broadcasters would need to be below 1 GHz.

The additional costs associated with supporting additional transmissions near (in frequency terms) existing broadcast transmissions will therefore include:

- The costs of additional transmitters and antennas.
- Alternative set-top boxes (STBs) for subscribers – although most subscription services require a new customised STB, implementation outside of the UHF band would require a non-standard RF receive module, the cost of which will be directly related to volume (of subscribers).
- Replacement of additional aerials for subscribers (depending on whether the pass-band of existing aerials is able to accommodate the new transmissions).

The very high cost of re-equipping households so they can receive services in a non-harmonised band suggests the band would be low relative to a harmonised band where incremental spectrum could be released by re-equipping a much smaller proportion of households to receive say DVBT-2 transmissions.

7.5 Conclusions

We have found it difficult to derive general estimates of the incremental commercial value of spectrum for broadcast networks. The reason for this is that value is specifically related to the content proposition, competing content propositions, the costs of content and content and coverage regulation in a way that does not apply to fixed and single site networks and that is less acute for cellular mobile networks.

In these other cases individual buyers/sellers can make infrastructure-spectrum trade-offs that provide a useful indication of value. In the case of TV broadcasting the configuration of the common transmission infrastructure determines the embedded base of consumer equipment so that it can be very costly for a single multiplex operator to agree changes in the infrastructure and maintain existing levels of reception of the service. This increases the scale economies associated with DTT service provision and affects the basis by which marginal spectrum values can be meaningfully derived for individual multiplexes or channels. We find that the marginal value spectrum used by TV broadcasting is likely to be determined by the business case for additional TV services rather than infrastructure cost/spectrum trade-offs. A similar situation applies in respect of local radio where changes in spectrum use may only yield commercially attractive blocks of spectrum if all broadcasters adjust their spectrum use.

A further complication is that in practice content regulation reduces the commercial viability of some services using some existing multiplexes and so affects marginal commercial spectrum values. While it may be possible to derive commercial values for incremental DTT spectrum that is not affected by existing content and coverage regulation, actual market values are likely to be indirectly affected by such regulatory constraints on existing capacity utilisation, so we have not pursued this option.

8 Conclusions

The main conclusions we draw from this study are

- There is no generic value of spectrum for a particular frequency range that is relevant to actual market transactions. Rather valuations are highly specific.
- The value of an increment of spectrum derives from either its use to make savings in the use of other resources (i.e. cost savings) and/or to generate additional net revenues.
  - In cases where there are substitutes for the use of spectrum, the value of spectrum depends importantly on the cost and functionality of those substitutes.
  - In cases where spectrum is used to deliver additional net revenues, expectations of future costs and revenues from the spectrum using service drive value.
- Valuations are specific to the market and regulatory situation being considered. We considered four generic network types – cellular mobile, fixed, single site and broadcast – and considered the value of incremental spectrum to a buyer in each case.
- The value of spectrum to a buyer could differ significantly from the value of spectrum to an incumbent user (i.e. a seller) because of transaction costs incurred by incumbent users if they have to vacate a frequency band. Many of these transaction costs derive from the need to replace complementary network assets and customer receiver equipment (and in some cases maintain service at a given quality level). The value of existing assets may be lost, contracts terminated and dual running of systems may be required if new assets take time to construct and test.
- Despite all of these caveats we find that:
  - The potential value is greatest from cellular mobile applications, followed by PBR then fixed links. There are orders of magnitude differences in value between these applications.
  - Although quantity of spectrum supply for a particular application is important it is not the main determinant of spectrum value. The degree of harmonisation is also influential.
  - Harmonised spectrum can be much more valuable than non-harmonised with the possible exception of PBR which has historically been a niche market using non-harmonised equipment.
  - Harmonisation is likely to be particularly important to the cellular mobile applications since the sector is reliant on scale economies in handset and network equipment supply. Leading markets face higher first mover implement costs where they attempt to utilise non-harmonised spectrum.
  - Harmonisation is also likely to be important for fixed links applications. Although a wide variety of bands are supported, there is supplier reluctance to support frequencies outside this set of supported bands.
  - In general use of spectrum for mobile applications has more value than for fixed applications in part because there are fewer alternatives for the former. This means that there will inevitably be a breakpoint in spectrum value at frequency ranges where mobile applications are not technically feasible because good non-line of sight coverage is not possible.
- More certain estimates of value would be possible if there was better information available on the characteristics of existing networks and users and unmet demand. This would enable more

realistic consideration of the choices facing spectrum users and so a better understanding of how they might value spectrum.

- In addition, an up to date view on the nature of spectrum in the bands under consideration is an essential starting point. For example, we found that certain bands used by fixed links were much less congested that we first thought and this perhaps indicates these bands are of declining value to these users. This may be because the attributes of other frequency bands are more attractive (e.g. more capacity, less interference, cheaper equipment) or use non-wireless transmission. The general point here is that value is changing over time as demand and supply conditions change and to estimate value at a point in time we need a good understanding of these trends.
- Comparisons between market values, calculated values and charges set by Ofcom can be problematic. In all cases like for like comparisons are rarely being made. Aside from differences in timing (and so market situations) the following factors need to borne in mind.
  - Spectrum that is auctioned is generally incremental to existing holdings which may be traded and so is likely to have a lower value (as it will be some time before it is used) than existing holdings all else being equal.
  - Some spectrum requires management by Ofcom and other spectrum is managed by users. Because Ofcom does not set a separate charge for its spectrum management activities this means that prices for managed spectrum would be expected to exceed those for user managed spectrum, all else being equal.
  - Regulatory conditions differ between frequencies – particularly those relating to harmonisation and sometimes other technical, coverage and content restrictions – and this can have a significant impact on value.