Topics in spectrum valuation benchmarking

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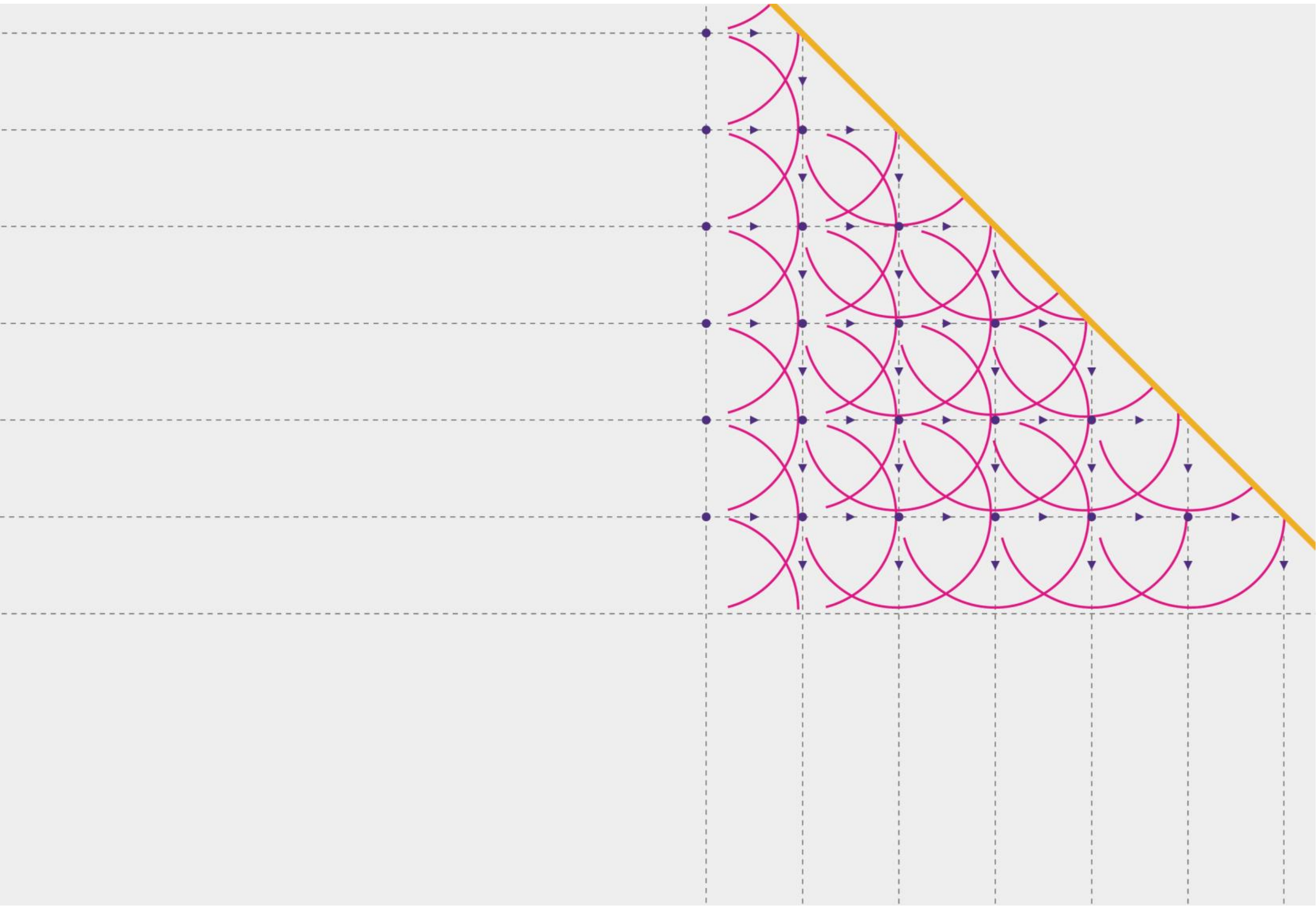

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About Plum

Plum offers strategy, policy and regulatory advice on telecoms, spectrum, online and audio-visual media issues. We draw on economics and engineering, our knowledge of the sector and our clients' understanding and perspective to shape and respond to convergence.

About this study

This study for the ACMA has been commissioned to investigate a number of topics surrounding the use of benchmarking techniques for valuing spectrum. Three discrete topics are investigated to assist the ACMA with their implementation of these techniques.

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1 Introduction

This report has been commissioned by the Australian Communications and Media Authority (ACMA) to assist in the application of spectrum valuation techniques when considering future spectrum awards and renewals in Australia. A significant number of spectrum licences are due to expire in the years between 2028 and 2032, and the ACMA has been researching a number of topics surrounding how these licence renewals or re-awards should be undertaken. In particular, Plum has carried out a number of previous studies identifying:

- International best practice in carrying out licence renewals, and
- Experience and best practice in spectrum valuation.

This new report has been commissioned to research and recommend actions in three key topics surrounding the ways in which benchmarking methods for spectrum valuation are applied.

1. Adjusted benchmarking is a method used to estimate the value of spectrum, particularly in cases where there are limited direct comparators or where it is suspected that a country may have significant geographic or demographic differences. The ACMA has asked Plum to look at different types of adjusted benchmarking and consider how these may be applied in Australia.

2. Both direct and adjusted benchmarking require the use of large datasets to ensure there is a robustness to results. However, with such large datasets it is expected that there will be some observations from countries which are less comparable to Australia. The ACMA has asked Plum to look at where weightings have been applied to benchmarking methods and the extent to which these have impacted results and conclusions.

3. When carrying out benchmarking analysis it is important that observations are normalised – that is, they are adjusted to account for differences in licence duration, or for the time since the awards were made. This report examines the ways in which these adjustments are made.

The remainder of this report examines each of these in detail.

2 The use of adjusted benchmarking

Perhaps the most common method of spectrum valuation is direct benchmarking, whereby a number of observations are gathered from auctions of the same or similar spectrum. Auction results are used since they represent a market value which reflects the value of spectrum to operators – as long as the auctions are appropriately designed, an efficient outcome will see spectrum users bidding at the level of their valuation. By benchmarking against a set of auction results for the same spectrum bands, a generally applicable value for spectrum (often measured in terms of per MHz per population) can be derived.

Such methods have been used extensively for established mobile and other spectrum, such as the 800 MHz, 900 MHz, 2100 MHz, and 3500 MHz bands. Regulators may use these methods for setting annual fees, for determining reserve prices are auctions, or for understanding the opportunity cost of one particular use of spectrum. Operators can use such methods to derive bidding strategies for new awards, to determine appropriate prices for spectrum transfers, or to value spectrum within the asset base.

However, this type of direct benchmarking relies on there being a sufficiently large dataset for comparison, so that outliers and country-specific factors are averaged out. For some spectrum bands – particularly those which have seen a recent change of use, or which have historically been awarded through direct awards or beauty contests, there may not be a sufficiently large number of existing auction results to benchmark against. For example, when the 3500 MHz spectrum was first identified for use by IMT, the first awards of the band could not rely on benchmarking data since previous awards had been made on the basis of spectrum being used by satellite base stations or fixed links.

2.1 Types of adjusted benchmarking

There are two main methods used for the adjusted benchmarking approach, the relative value (or ratio) method and the distance method. These have been described at length in Plum’s previous report on spectrum valuation methodologies. Adjusted benchmarking Is generally used when there are not sufficient data points for direct benchmarking. Adjusted benchmarking is also used to account for country specific factors which might not be accounted for by direct benchmarking, producing more like-for-like comparisons. A short description of each, and appropriate country examples are outlined below.

2.2 Relative value method

The relative value method makes use of value ratios for various frequency bands. Bands and band groupings are estimated from international benchmarks. There can be many possible combinations that can be used, but generally the ratios are derived by comparing the value of a particular frequency band to be examined, for example the 2 GHz band, to the values of another common mobile spectrum band (such as the 700 MHz, 1800 MHz, 2100MHz bands) for selected comparator countries. If this method were to be used for other services, then other spectrum bands already used for that service should be chosen for a comparator.

The reference band is a band that has been assigned in the country concerned and all other comparison countries. As the comparison countries are usually ones with similar characteristics to the country concerned, their value ratios should largely account for any underlying country specific factors. The adjusted benchmarking data for the relative value approach are prepared in the same way as the direct benchmarking data, and as such considerations for dataset selection apply. Data adjustments include but are not limited to frequency characteristics, licence conditions, data adjustments, and adjustments for inflation.

These value ratios are then used to derive an equivalent value of the band in focus. As with direct benchmarking, the results for the band values produced by adjusted benchmarking are reported in AUS/MHz/population.

If we are trying to estimate the value of the 3500 MHz band in Australia, we first look at the spectrum values for the 700 MHz, 1800 MHz and 3500 MHz bands in multiple countries, with similar, geographic, market and socioeconomic characteristics. To estimate values for the 3500 MHz band in Australia we can multiply:

- The 700 : 3500 ratio by the Australia 700 MHz value; or
- The 1800 : 3500 ratio by the Australia 1800 MHz value.

Additional references can be used at the discretion of the regulator, based on the availability and reliability of auction data.

2.2.1 Case study: relative value method for 28GHz band in Taiwan

Figure 2.1shows the values of different spectrum bands relative to the 3.5 GHz band, for countries which had recently auctioned the 3.5 GHz spectrum before 2019 when this analysis was undertaken. The 700 MHz, 1800 MHz, 2100 MHz and 2600 MHz bands were chosen as reference points, as these were the bands with recent Taiwan auction values for reference.

Figure 2.1: Relative value ratios with reference to 3.5 GHz band

Country	700 MHz	1800 MHz	2100 MHz	2600 MHz	3.5 GHz
Australia[1]	6.57	0.67	0.65	0.11	1
Australia[2]	7.39	0.75	0.73	0.12	1
Austria	-	15.26	-	0.79	1
Czechia	-	12.60	-	3.20	1
Finland	5.16	-	-	-	1
Germany	1.35	1.94	1.41	0.18	1
Ireland	-	2.52	-	-	1
Italy	1.56	0.76	-	0.18	1
Saudi Arabia	17.07	7.90	-	0.91	1
South Korea	-	2.19	3.17	1.17	1
Spain	-	-	-	0.20	1
UK	-	-	-	1.55	1

There is significant variation in the value of 3.5 GHz and this is also reflected in the value ratios. Aside from the 700 MHz : 3.5 GHz ratio which is consistently above 1 (that is, 700 MHz is more valuable compared to 3.5 GHz), the ratios for the rest of the bands (1800 MHz, 2100 MHz and 2600 MHz) comprise values below and above 1, indicating that it is not clear that 3.5 GHz is always lower in value than these bands. In light of this analysis, the regulator did not consider adjusted benchmarking to be the most reliable method for the 3.5 GHz spectrum in

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[1] Auction values from December 2018 spectrum auction.

[2] Auction values from December 2017 spectrum auction.

Taiwan at that point in time. Econometric analysis and other statistical methods provided a more thorough means of estimating the spectrum value.

Figure 2.2: Relative value ratios with reference to 3.5 GHz, based on median values[3]

700MHz	1800 MHz	2100MHz	2600MHz	3500MHz
5.87	2.19	1.07	0.50	1.00

Figure 2.3 shows the relative-value ratios for the 28 GHz band. The 28 GHz band is clearly much less valuable compared to the rest of the mobile bands as indicated by the value ratios (see Figure 2.4), although there is still substantial variation in some of the ratios. Given the small sample size of the ratios, the regulator used the median values for the observed ratios as shown in Figure 2.4 as a proxy to apply to the Taiwan reference values to generate the 28 GHz value estimates.

Figure 2.3: Relative value ratios with reference to 28GHz band

Country	700 MHz	1800 MHz	2100 MHz	2600 MHz	24-28 GHz
Ireland	-	69.06	-	-	1
Italy	207.70	101.53	-	24.21	1
South Korea	-	52.78	76.45	28.28	1
US	32.15	57.42	263.39	-	1
US	22.98	41.05	188.32	-	1

Figure 2.4: Relative value ratios with reference to 28GHz, based on median values

700MHz	1800 MHz	2100MHz	2600MHz	28GHz
32.15	57.42	188.32	26.25	1.00

Figure 2.5 shows the results of the adjusted benchmarking for the 28 GHz band. The estimated value range in terms of TWD/MHz/pop is from 0.09 to 0.57.

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[3] The median is the middle value in a series ordered from least to greatest. As the median is the middle number in a set of data observations, it does not get influenced by the low or high value outliers.

Figure 2.5: Adjusted benchmarking results for 28GHz band [4]

Reference band (year)	Taiwan reference value* (TWD/MHz/pop)	Relative-value ratio compared to 28 GHz	28 GHz estimate value (TWD/MHz/pop)
700 MHz (2013)	22.2	115.3	0.19
1800 MHz (2013)	40.8	71.3	0.57
1800 MHz (2017)	10.4	71.3	0.15
2100 MHz (2017)	14.9	169.9	0.09
2600 MHz (2015)	10.9	26.2	0.41

As shown in in the example above, where there are large variations in the relative value ratios the results may not be useful, and as such other techniques such as econometrics may be better at determining an appropriate band value. One significant point to be raised is that when using the relative value method, if there are large outliers and large variations (very low and very high as seen in this example) in the value ratios, the mean of the value ratios for the countries being used as benchmarks may not be informative. Plum has used medians and geometric means to determine the average value ratios in the past.

Medians are generally used when observed values are not normally distributed – that is, when the range of the values is irregular with potentially some very small and very large values. Using the simple mean would lead to spurious descriptive analysis, as very large values would unduly increase the average. In such cases, medians are used as an alternative. The geometric mean is the average of the product of different observations under consideration. One way to think about this is as a compounded annual growth rate. The geometric mean is often used when working with percentages, which are derived from values, while the standard arithmetic mean works with the values themselves. If the numbers are volatile, the geometric mean is a better estimate than simple average.

2.2.2 Case study: relative value method for C-band spectrum in Bahrain

In 2020 Plum produced a pricing report for the TRA to determine the best way to release C-band spectrum to operators in Bahrain. The 3.5 GHz band was the band in focus, with comparator countries similar in demographic and socioeconomic characteristics to Bahrain, who had already released the 3.5 GHz and 2.6 GHz bands. As a result the value ratios indirectly accounted for the country-specific factors in Bahrain.

Adjusted benchmarking of the 3.5 GHz band was carried out based on the relative value ratios from a set of comparison countries. The countries used in the adjusted benchmarking dataset were countries which were similar in characteristics to Bahrain and had assigned the 3.5 GHz and 2.6 GHz band. The figure below shows the values of the 2.6 GHz and 3.5 GHz bands in comparison countries and their respective value ratios.

Figure 2.6: Reference band values and ratios from comparison countries (BHD/MHz/Pop) (2020 prices)[5]

Country	2.6 GHz values	3.5 GHz values	2.6:3.5 relative ratio
United Kingdom	0.046	0.049	0.930
South Korea	0.172	0.090	1.898
Spain	0.006	0.038	0.160

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[4] Note: * The Taiwan reference values have been adjusted for inflation and to reflect a licence duration of 21 years

[5] Note: Relative ratios provided are based on unrounded data; please exercise caution when interpreting and in recalculation.

Country	2.6 GHz values	3.5 GHz values	2.6:3.5 relative ratio
Finland	0.157	0.016	10.020
Italy	0.034	0.156	0.221
Austria	0.017	0.022	0.753
Australia	0.013	0.098	0.128
Saudi Arabia	0.00003	0.010	0.003
Latvia	0.002	0.036	0.044
Germany	0.013	0.066	0.191
Hong Kong	0.232	0.044	5.325
Taiwan	0.111	0.241	0.459
Singapore	0.116	0.014	8.070
Belgium	0.039	0.003	11.869
United States	0.007	0.096	0.069

We can see that there is a lot of variation in the value ratios of the 2.6 GHz : 3.5 GHz spectrum for our data set of countries. This was largely driven by some of the low value 3.5 GHz assignments, including some recent competitive tender and direct award assignments in Singapore and Belgium at the time and an early 3.5 GHz assignment from Finland when the demand for 5G was uncertain. Hong Kong's value ratio is also an outlier because of the high value of its 2.6 GHz auction of March 2013 when the demand for LTE services was very high. As a result, it is likely that the mean of these value ratios would get influenced by these outliers. To account for this variation, we used the median and the geometric mean to determine the average value ratio of the 2.6 GHz : 3.5 GHz spectrum, to estimate the value of the 3.5 GHz band for Bahrain.

Figure 2.7: Averages of the 2.6 to 3.5 GHz value ratios[6]

Value ratio	Mean [not used due to outliers]	Median	Geometric mean
2.6 GHz to 3.5 GHz	2.6760	0.4595	0.4882

This particular case study is interesting because there are two relevant values of the 2.6 GHz band that we considered. First, there was the auction of additional spectrum, which allocated an additional 10 MHz of spectrum to each of Batelco and Zain. While this did represent a market value of spectrum, it is likely that the price was inflated due to a low amount of bandwidth for sale, a low price for a basic spectrum portfolio which was awarded at the time, and the use of a first-price sealed bid auction. Second, this basic spectrum portfolio, of 40 MHz awarded to each operator, reflects the likely award process for the 3.5 GHz spectrum, but is not directly set by the market – although the price was set by the TRA using international benchmarks at the time. It must be noted that both these awards were in addition to the annual fees that are payable on spectrum in Bahrain.

From these two award processes, we can calculate the value of the total price paid for spectrum, by adding a NPV of the annual fees over the licence period to the sum paid. This calculation gives us a value of:

- 0.0336 BHD/MHz/pop for spectrum in the basic spectrum portfolio;

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[6] Note: Relative ratios provided are based on unrounded data; please exercise caution when interpreting and in recalculation.

- 0.0899 BHD/MHz/pop for spectrum awarded at auction

The figures above are then used to calculate values for the 3.5GHz spectrum, this is accomplished by multiplying the 2.6GHz values by the 2.6GHz : 3.5GHz value ratios from Figure 2.7.

Figure 2.8: Equivalent 3.5 GHz values in Bahrain, Spot (BHD/MHz/pop)

Equivalent value	Median	Geometric mean
3.5 GHz band in basic portfolio	0.0129 (0.0336 x 0.4595)	0.0154 (0.0336 x 0.4882)
3.5 GHz band in additional spectrum	0.0346 (0.0899 x 0.4595)	0.0413 (0.0899 x 0.4882)

2.3 Observed distance ratios

The alternative to relative value benchmarking is observed distance ratios. This methodology involves a distance ratio derived by generating benchmark values using two different reference bands, in order to estimate the value of a third band.

In the example below, benchmark values for bands in the 800 MHz and 2.6 GHz bands are used to estimate the value of 1800 MHz spectrum. The method is calculated as the “Y/X” ratio and is expressed as a percentage. Relating this to the corresponding 800 MHz and 2.6 GHz values in Australia for example, and expressed as a formula we have:

$$\frac{1800_{BC} - 2.6_{BC}}{800_{BC} - 2.6_{BC}} \cdot (800_{AUS} - 2.6_{AUS}) + 2.6_{AUS}$$

where: AUS represents Australia and BC represents the benchmark country (or average of countries).

The “X/Y” ratio is calculated as the difference in value between the 1800 MHz and the 2.6 GHz (“Y”), divided by the difference in value between the 800 MHz and the 2.6 GHz (“X”), which is referred to as the “X/Y” ratio.

In this method, fewer observations are required as compared to the relative value approach, but the comparator countries used for benchmarking must be considered carefully. Usually this is done using some sort of tiering or cohort analysis based on a number of factors, further discussed below. The quality of evidence for tiering would include the following.

- That the auction process is likely to have been determined by a market driven process of bidding (meaning spectrum was not driven by reserve prices).
- Based on available evidence the relative process in the auctions are at least as likely to be based on the bidders intrinsic valuations of spectrum as on strategic bidding.
- The outcome of the auction should be informative of forward looking relative spectrum values in Australia, considering country specific circumstances and auction dates.

Often there is a risk of understating or overstating the distance method value of spectrum when constructing relative values. The biggest drawback of the observed distance method is that it will not produce as much of a like-for-like comparison, unlike the relative value method. A worked out example from Ofcom’s consultation in 2018 for the 1800 MHz spectrum is provided below; a number of countries were used as benchmarks but we have provided Czechia as exemplar here.

Figure 2.9: Summary of 800 MHz, 1800 MHz, and 2.6 GHz spectrum values in Czechia (2018 Prices)[7]

800 MHz (£m/MHz)	1800 MHz (£m/MHz)	2.6 GHz (£m/MHz)	Distance method (£m/MHz)
52m	21.3m	5.5m	14.9m

Figure 2.10: Summary 800 MHz and 2.6 GHz Spectrum market values in the United Kingdom (2018 Prices)[8]

800 MHz (£m/MHz) net expected costs	800 MHz (£m/MHz) gross expected costs	2.6 GHz (£m/MHz)
32.2m	35.5m	5.9m

This results in a calculation as below[9].

$$\frac{21.3_{CR} - 5.5_{CR}}{52_{CR} - 5.5_{CR}} \cdot (32.2_{UK} - 5.9_{UK}) + 5.9_{UK} = 14.9$$

There are a number of considerations when using the distance method, as stated previously. Firstly the benchmark countries used must be countries where the auctions had no limits on participation, where spectrum caps were not binding to the bidders, and where the spectrum was sold above reserve price; the reason for these considerations is to make sure the spectrum is reflective of the true market value. As mentioned previously, the countries chosen for this method must be carefully considered as there is a risk of understating or overstating the true value of the spectrum. As such, the distance method is implemented alongside an "assessment of risk" profile which comments on the probability overstating or understating the value of spectrum for each country chosen. An example of this will be seen in the United Kingdom case study provided below. Similarly, particularly onerous licence obligations on operators may influence auction prices and this must be considered when selecting countries as benchmarks.

Additionally, the lot structure and location of the bands carry risks of understating the distance method benchmark – this was noted by Ofcom in 2015 that lots located between existing spectrum holdings may have different values to operators depending on their existing holdings, and may reduce the intensity of competition for the lots being considered for benchmarking. Lastly, combining the prices of different auctions for different years carries a risk that the gap in time may contribute to a risk of understating or overstating the value of the spectrum, and can thus have a commensurate effect on the distance method benchmark.

To summarise, generally the selection of benchmark countries is done using a 3-level tiering approach. A country with a high risk of understated values based on the factors described above will be a tier 3 for example, but a country with a relatively low risk of understated/overstated values will be tier 1.

2.3.1 Case study: distance ratios in the United Kingdom

Ofcom went through a lengthy consultation regarding the annual licence fees for the 900 MHz and 1800 MHz spectrum bands from 2013 to 2018. Ofcom used the distance method of adjusted benchmarking to derive appropriate values for the 900 MHz and 1800 MHz bands. Nineteen countries were used in the benchmarking process. Alongside the benchmarking were assessments of the risk that they overstated or understated market

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[7] Source: Ofcom 2018, "Annual Licence Fees for 900 MHz and 1800 MHz frequency bands – Annexes", available at https://www.ofcom.org.uk/siteassets/resources/documents/consultations/category-2-6-weeks/114665-annual-licence-fees/associated-documents/annexes-1-6.pdf

[8] Source: Ofcom 2018

[9] Caution should be exercised when revising this calculation as the example provided is from the UK regulator Ofcom and has been rounded to 14.9 where the actual calculation will yield a result of 14.836.

values given different countries used different processes for auctions, technology advancements may change the value of different spectrum and local competitive dynamics may influence bidding.

The case study country chosen here is Czechia, as it was used in the previous section as a numerical example, to demonstrate how the distance method has been applied by an international regulator.

Ofcom first made an assessment of the 1800 MHz and 2.6 GHz paired and unpaired spectrum awards that took place in Czechia in 2016, the results of which are set out below. This is done for all nineteen countries, who are then ranked from Tier 1 – Tier 3 based on criteria including

- Whether award outcomes are likely to reflect market values
- Whether coverage obligations influence demand for spectrum
- How lot structure and internal competitive dynamics between MNO's affect demand for spectrum
- Technological developments, trends in data traffic growth, revenues, profits or network costs may cause the regulator to make further adjustments to estimates of market value

The categorization information is to determine the extent to which the prices of the spectrum sold is reflective of the market value in Czechia and further, whether the value of the 1800 MHz spectrum would have been likely to reflect UK market value. A risk assessment of each of the countries is then presented alongside the distance method benchmark and the average of all tier 1 countries is used for pricing.

Figure 2.11: June 2016 1800 MHz and 2.6 GHz results, 2016 Prices[10]

	1800 MHz	2.6 GHz paired	2.6 GHz unpaired	Price paid (CZK)
Total Available	**2x15.8**	**2x10**	**50**	**2.6bn**
Telefonica	2x10.8	-	25	1.5bn
T-Mobile	-	2x10	25	0.7bn
Vodafone	2x5	-	-	0.4bn
Unsold	-	-	-	-

Figure 2.12: June 2016 1800 MHz and 2.6 GHz auction features in Czechia[11]

	Description	Comment
Number of bidders; number of lots; lot sizes	1800 MHz: In 2016, there were three bidders. Spectrum was awarded in two 2x5 MHz and two 2x2.9 MHz lots. 2.6 GHz: in total 70 MHz of 2.6 GHz spectrum was awarded; paired spectrum awarded in one 2x10 MHz lot, and un-paired in two 25 MHz lot	This 1800 MHz spectrum was initially auctioned in the 2013 multiband spectrum auction when it was reserved for new entrants and auctioned in one lot of 2x15.8 MHz lots, but went unsold. Most of the paired 2.6 GHz was assigned in 2013 (2x10 MHz was unsold), whilst all un-paired spectrum went unsold.

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[10] Source: Ofcom 2018
[11] Source: Ofcom 2018

	Description	Comment
Spectrum caps/restriction	1800 MHz: a spectrum cap of 2x30 MHz including existing holdings. 2.6 GHz: no cap applied	In the 2016 auction, the 1800 MHz spectrum cap was not binding for any of the winners.
Reserve prices	1800 MHz CZK 75.0 million per 2x2.9 MHz lot, and CZK 130.0 million per 2x5 MHz lot. 2.6 GHz: CZK 138.0 million per 2x10 MHz lot.	The reserve prices are based on the 2013 auction reserve prices adjusted for a shorter licence length (the licence end date was aligned with the spectrum auctioned in 2013)
Obligations	1800 MHz: Obligation to provide coverage to 20% of the population within seven years, with a minimum download speed of 2Mbps, increasing to 5Mbps after this period. 2.6 GHz paired: Obligation to provide coverage to 10% of the population within seven years, with a minimum download speed of 2Mbps, increasing to 5Mbps after this period.	The coverage obligations for 1800 MHz are less onerous than in the 2013 auction. The requirements on 2.6 GHz spectrum are identical to the earlier requirements
Other factors	Licence length: the Czech 1800 MHz licence is for 13 years. Annual licence fees apply	

It is possible that the Czech distance method benchmark would understate or overstate the value. Ofcom considered the risks as follows.

- It was noted that there were no bidding restrictions on the participants, and the 1800 MHz spectrum cap was not binding for any of the participants; as such, it was considered that the 1800 MHz auction price reflected a market-driven process.

- However, the lot structure and location carry a risk of understating the Czech distance method benchmark.

- Ofcom combined auction prices from different auctions in different years, 2013 (800 MHz) and 2016 (1800 MHz and 2.6 GHz). There is a risk that this gap in time affects the risk of understatement or overstatement, although there was no identified clear direction or magnitude of the possible effects. Based on this assessment, it was thought that there is a risk of understatement to the distance method benchmark.

Czech auctions were considered Tier 1 for the following reasons:

- The auction prices of 800 MHz, 1800 MHz and 2.6 GHz were all above reserve. This would suggest that the auction prices were primarily determined by a market-driven process of bidding.

- Based on the evidence available, it was considered that the relative prices in the auction are at least as likely to be based on bidders' intrinsic valuations of spectrum as on strategic bidding.

- The Czech auction outcome appears likely to be informative of forward-looking relative spectrum values in the UK, having considered country-specific circumstances and the timing of these awards.

Figure 2.13: Summary of evidence points from Czechia (2018 prices)[12]

	Absolute values (£m/MHz) 800 MHz	Absolute values (£m/MHz) 1800 MHz	Absolute values (£m/MHz) 2.6 GHz	Relative value benchmarks (£m/MHz) Distance method
Final Values	52.0	21.3	5.5	14.9
Assessment of risk	No risk identified	Risk of understatement	No risk identified	Risk of understatement

Finally cross checks of all absolute values of the auctions are performed for every country in order to mitigate the risk of understating or overstating a particular award. This is done in the following ways:

- By comparing the ratio of estimates of 1800 MHz to 900 MHz lump-sum values in the UK to the corresponding ratio for benchmark countries where both bands were awarded.
- By comparing the average of Tier 1 countries, and the average of Tier 1 and Tier 2 countries, within each band.

2.3.2 Case study: distance ratios in Mexico

In 2015 the Mexican regulator, the IFT, was seeking to set spectrum prices for a wide variety of bands, including some which had not been awarded before. Within ITU Region 2, there were few countries where the 800 MHz and 2500 MHz bands had been used, due to the legacy configurations of 850 MHz, and use of 2500 MHz by fixed links; the only exceptions were countries which had significantly different economic and demographic indicators.

Given this, the IFT was recommended to use the 2010 auction for 1900 MHz and AWS spectrum as reference points, allowing for a comparison which took into account differences between countries. The 800 MHz band was not directly comparable to either of these bands, given the differences in propagation and usage, and as a result the use of two different reference points was considered to give a more robust analysis.

2.4 Choice of methodology

There are a number of potential reasons for using one method over the other.

The distance method works best when comparing frequency bands for which the values, relative to one another, are unambiguous. For example this has been applied in the UK to estimate the value of 1800 MHz using 800 MHz and 2.6GHz as reference bands, which is made possible since the 800 MHz values for all the selected benchmark countries are higher than the corresponding 1800 MHz values, which are also higher than the 2.6 GHz values. This monotony of relationship means that it is possible to work out the value of the 1800 MHz using the corresponding distance ratios.

On the other hand, if a country has two bands that are too similar in terms of propagation characteristics and the direction of the value of the difference of the bands is uncertain, distance method adjusted benchmarking may not be very useful. As an example, comparing the PCS and AWS bands – where the PCS is higher in certain countries but AWS higher in others – if those bands are used as references to estimate the value of a third band (for example the 800 MHz band) then the resulting estimates of this would be highly variable and not

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[12] Source: Ofcom 2018

informative. As such caution should be used when assessing the suitability of the distance method in studies. The relative value method does not suffer from this issue since only one reference point is used.

The distance method does require observations where a larger set of spectrum bands has been awarded – all comparator countries must have awarded the two reference bands and the band being examined. In most cases this restricts the number of comparators, and there is the possibility that there will be too few comparators to be able to draw a conclusion. However, the analysis itself is more robust as each observation contains more data, and will automatically adjust for country-specific factors. For example, if Country A were to always have spectrum values double the international average (due to, say, high population density, high income and ARPU levels, and restricted alternative spectrum availability), then the ration between 1800 MHz and 2600 MHz would be the same as for other countries which had lower absolute values.

However, if a result in a certain band used for comparison is much higher than the others in that same country, due to for example market circumstances at the time of auction, rather than specific characteristics of the band then results will be skewed, and with a smaller set of comparators this can lead to a less robust result.

Figure 2.14: Advantages and disadvantages of adjusted benchmarking methodologies

Valuation methodology	Advantages	Disadvantages
Relative value method	• Can use individual bands or band groupings with similar propagation and country characteristics for flexibility. • Produces like-for-like comparison between countries. • Likely to be larger datasets due to only needing two spectrum bands awarded.	• Market circumstances at time of auction may skew results for similar bands. • Difficult where there are few datapoints. • Relative value ratios that are significantly higher or lower than reference band will not be informative.
Distance method	• Works best when comparing frequency bands for which the values in relation to each other are unambiguous. • Actual country benchmark prices or proxy prices can be used for bands, ensuring flexibility. • Fewer countries are needed to achieve robust estimates (but there will be fewer comparators which have awarded all reference spectrum). • Automatically takes into account country-specific factors when reporting on distance ratios.	• Difficult where observed values for comparator bands differ significantly. • Lot structure and location of bands may influence benchmark values. • Large time gaps between auctions may understate or overstate distance method value. • Market value of spectrum at time of auction may not be reflected in benchmark countries. • Produces less of a like-for-like comparison between countries.

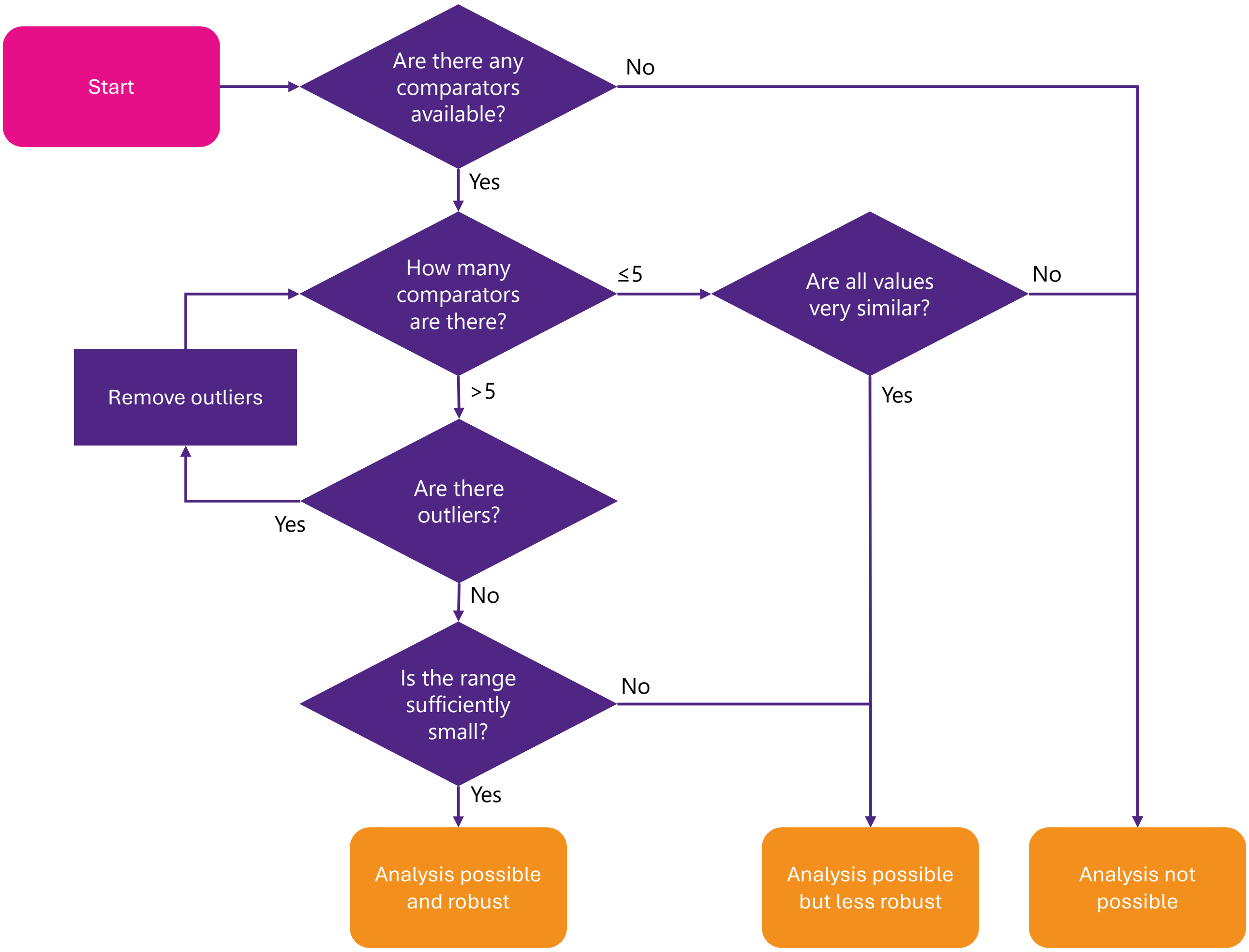
2.5 Robustness of results

The ACMA has asked whether there are a specific number of observations and comparators that are needed to make adjusted benchmarking robust. As this is not a statistical regression method, there are no defined degrees of freedom or other statistical tests which will automatically give a number of observations that are required for robustness. Instead, we must consider the distribution of values, in terms of the range and the shape of a frequency chart.

Essentially, there must be sufficient observations to ensure that outliers can be identified and eliminated, and that the resulting range is not too large. In our experience with direct benchmarking, it can be sufficient to have around five observations to be able to be confident that the comparator sample is representative, although (as can be seen from the analysis we use as examples in Section 3.1.1) even with significantly more than this number we often still find a large range of possibilities. For adjusted benchmarking, where it is important that each country has observed values for each of the anchor bands, the number of potential comparators may be much lower. In adjusted benchmarking, rather than comparing the values of spectrum, we are comparing the ratios of values instead.

Since there is no definitive answer as to how many observations are needed, an analytical flowchart can be used to determine where analysis is possible, and if so if it is likely to be robust. This is shown below.

Figure 2.15: Flowchart to determine robustness of analysis



In general, our benchmarking of spectrum valuation (or of the ratios used for adjusted benchmarking) does not result in a single number, but instead provides a range of values. This range is generally informed by four metrics.

- The mean of observations. This can be heavily influenced by outlier values, so it is important these are removed from analysis.
- The standard deviation of observations. With fewer observations the standard deviation tends to be much larger, meaning that the range in which we are confident the values sits can become unhelpfully large.

- The median of observations. Unlike the mean, this is not unduly influenced by large outliers, but it can instead be biased depending on where there are a cluster of observations.
- A range between the first and third quartiles. This presents the centre 50% of observations. It is not impacted by outliers but can be a very large range, especially if there are lots of observations.

If the mean lies within the last range, and particularly if it is close to the median, then the results are more likely to be robust.

2.6 Application of adjusted benchmarking

When applying these valuation methods there are a number of specific issues that must be considered.

2.6.1 Choice of comparator bands

The bands chosen must have similar propagation characteristics and have similar valuations across different geographies and timelines. It is particularly important that the services run over spectrum are the same, as otherwise the value that can be obtained from use of spectrum will be incomparable.

There may be difficulties in comparing a band where there are few datapoints for comparison other than established mobile bands where the observed values may vary significantly, this is due to natural supply and demand dynamics and technological advancements that may increase the value of certain bands due to enhanced data speeds and capacities. An example of this in practice may be unsold spectrum in any of the three bands being used, or a very large time gap between the auctioning of the bands being used for calculation. Lastly, if any of the three relevant bands was sold at its reserve price, this may not reflect the true market value, likewise if the incumbent was barred from bidding.

An advantage of the distance method here is that where there are country-specific factors that drive spectrum value, these may well apply to both of the comparator reference bands – meaning that the ratios between bands are more consistent between countries.

2.6.2 Choice of benchmark countries

The choice of benchmark countries as such should reflect the broad conditions of Australia in terms of geography, demographics, telecommunications industry structure, or technology progress. In this respect, cohort analysis and different weightings for country specific factors are useful tools to make the analysis more robust, a discussion of which follows in Section 3.

2.6.3 Regional variations and refarming stages

As well as economic and demographic similarity, we must also consider the spectrum band plans for comparator countries. Australia sits in ITU Region 3, meaning that it broadly shares a band plan with Asian countries, with (for example) historic awards of 850 MHz and 1800 MHz, and expansion of the 3500 MHz band. It is important that this is taken into account when deciding on comparator countries so that, for example, the 700 MHz band in France – which was assigned around a decade later and was used to launch 5G services – is not considered a direct comparison.

Within regions there may also be variance in use. In some countries the 900 MHz band, which was originally used for 2G or 3G services, may not be repurposed for expanding the LTE band. The refarming will lead to increases in the value of spectrum, meaning that direct comparisons may not be possible.

2.6.4 Other drivers of spectrum value

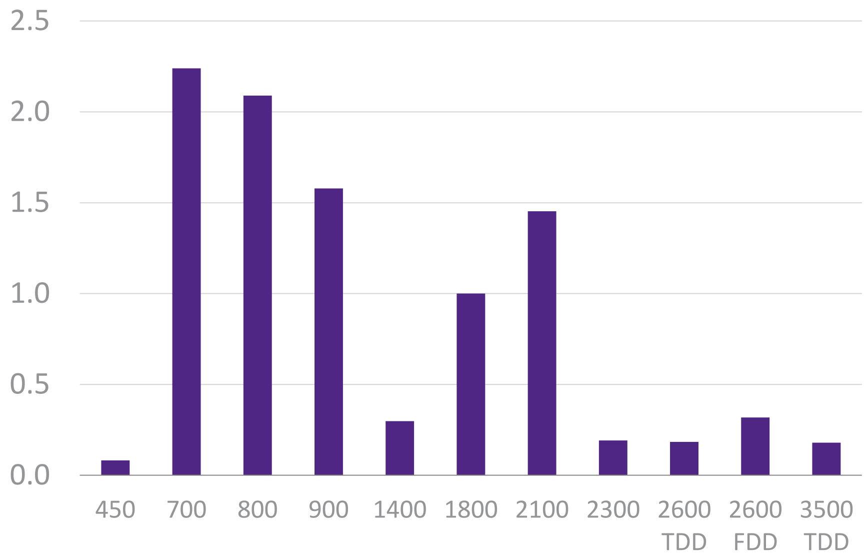
Other considerations such as previous frequency licence conditions (licence duration) and rollout or coverage obligations can all materially influence how comparable countries are. Additionally, the timing of auctions and past prices may reflect technology choices available and market expectations at the time, and may vary materially, as such it is important to investigate the underlying conditions leading to an award before deciding on certain bands in certain geographies.

2.7 Additional case study: mobile spectrum fees in Israel

As discussed previously there have been a number of examples of regulators using adjusted benchmarking in cases where there were few observations for a particular band. However, the fact that adjusted benchmarking is anchored on a valuation from the country being analysed means that this technique can be used in other ways.

In 2018, the Ministry of Communications in Israel was examining the fees paid for all spectrum bands. For mobile spectrum, annual fees had been set when spectrum was first awarded in 1995, and these were set at a standard price per MHz (which was subsequently adjusted for inflation). With the award of higher frequency bands, the Ministry was informed by operators that the standard price per MHz was unrealistic. To consider this, the Ministry commissioned analysis of the relative value for each band, resulting in levels shown below.

Figure 2.16: Indexed per-MHz spectrum values for application in Israel (1800 MHz = 1.0)



Overall the value for sub-1 GHz spectrum was found to be much higher than the value for spectrum at 2600 MHz and 3500 MHz. The Ministry decided, based on this analysis, to reduce the prices for these latter two spectrum bands, roughly in proportion to the ratio between them and the 1800 MHz band benchmark value. The Ministry did not, however, increase the spectrum price for lower-frequency bands.

3 Weighting in benchmarking methodologies

When carrying out benchmarking[13], as previously described, it is crucial that there is a large sample of competitors to ensure that the results are sufficiently robust. However, any increase in the number of observations is likely to lead to the inclusion of countries which are different to Australia in terms of geography, demographics, telecommunications industry structure, or technology progress. It is not realistic to expect that the value for spectrum in Australia would be as high as, for example, a densely populated, technologically-advanced country such as Taiwan; on the other hand the value would be expected to be higher than that seen in a lower-income and less-competitive market such as Fiji.

Faced with these differences, there are two potential methods of adjusting the benchmarking methodology. First, cohort analysis can be used to run multiple benchmarks for subsets of the dataset, with resulting ranges of results. Second, weightings can be applied to each observation, meaning that countries which are more similar to Australia are given greater prominence in the analysis.

3.1 Cohort analysis

The simplest method of applying a weighting to analysis is to remove all observations which are sufficiently different from Australia. The rationale for this analysis is that it would be expected that the value of spectrum is driven by the profits and revenue that an operator can expect to received from its customer base, and these profits and revenue will be, for example, higher in high-income countries, or lower in countries with greater levels of competition. Given this it is unrealistic to consider benchmarks from low-income countries, or countries with six MNOs, when trying to derive the value of spectrum in Australia.

There is a considerable amount of flexibility in how cohort analysis can be carried out. There is no defined or consistent way to determine whether an observation is sufficiently similar to Australia in each parameter. For income levels, it could be argued that the UN’s classification of Developed, Developing, and Least Developed countries could be used to narrow the observation base to only those in the same category; there is no equivalent, however, for population density. When considering the market structure, suitable comparator sets could include only those countries with the same number of operators, or those with the same level of competition (so, say, three, four or five operators), or those with a similar HHI (say, for example, within 100 points either way). As well as intuitive consideration of how similar a market is, consideration must be given to the number of observations that remain with each cut-off. Different assumptions over the appropriate cut-off could lead to different outcomes of analysis, particularly when there are outliers in value which sit on the margins of whether observations should or shouldn’t be included.

To avoid this issue, sensitivity analysis must be run, varying the level of cut-off for each cohort to ensure that there are not large variations in value. For example, if it were decided that population density should determine inclusion, and the population density index should lie between 80 and 120 (with the Australian population density indexed at 100), then the analysis should also be undertaken with cut-off ranges of [75, 125] and [85, 115]. If the resulting benchmark varied considerably in any of these cohorts, care must be taken in its application.

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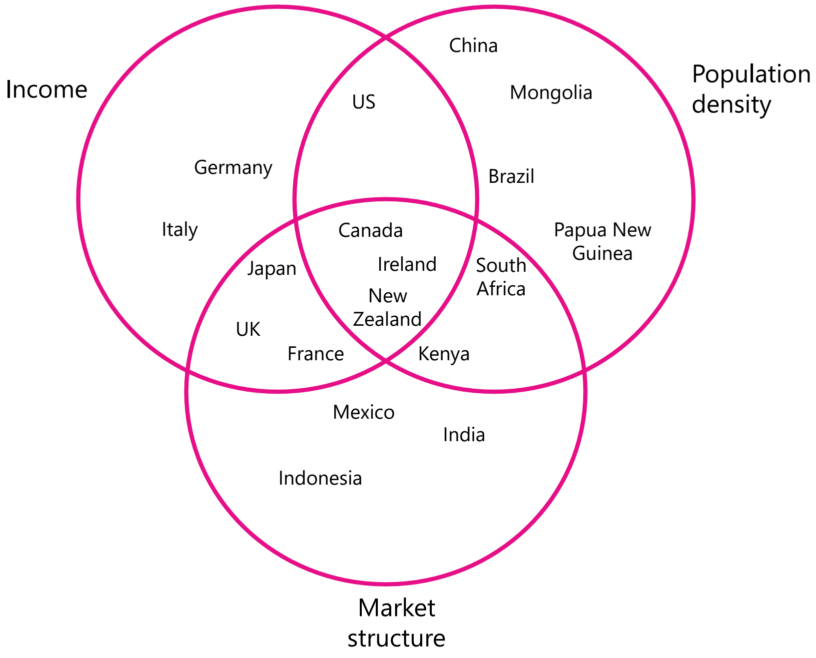
[13] The analysis in this chapter applies to both direct benchmarking and adjusted benchmarking. However, due to the lower number of observations typically included in adjusted benchmarking analysis, then any weighting or selection of observations is likely to have a much larger impact on results, and so such adjustments must be applied with caution.

3.1.1 Multiple parameters in cohort analysis

It is likely that there is no single parameter which would define whether a country is sufficiently similar to Australia to include in comparisons; indeed, we have already listed a number above. A country such as Singapore may have a similar income level, but is very different in terms of market structure and population density.

One option to deal with multiple parameters in cohort analysis is to simply continue to remove observations which are sufficiently different. However, such analysis can be very problematic as it can reduce the number of comparators to an unfeasible level. For example, in Figure 3.1 below, there are three parameters being considered. Any country found within one of the circles is considered to be comparable – so, for example, the US, Canada, Ireland, Italy, Japan, the UK, Germany, New Zealand and France are all considered to be sufficiently similar in terms of income level. There are some countries which are similar in terms of two parameters. However, of the eighteen countries listed – all of which are considered to be comparable in at least one way – only three are deemed to be comparable in all ways. Running a benchmark on this small subset would not be robust.

Figure 3.1: Impacts of multiple cohort analyses



Instead, in order to consider the impacts of multiple parameters, we tend to run multiple cohort analyses, and compare these to obtain an overall range. Figure 3.2 provides some example results from a recent study we carried out looking at an appropriate benchmark for 2100 MHz spectrum. This analysis was undertaken using two different exchange rate profiles[14] – spot rates and PPP – and cohorts were run on income level, population density, and the number of MNOs in the market.

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[14] Further information on appropriate exchange rates can be found in our previous paper for the ACMA, "International experience in spectrum valuation methodologies".

Figure 3.2: Example benchmarking results for 2100 MHz spectrum (Spot and PPP)[15]

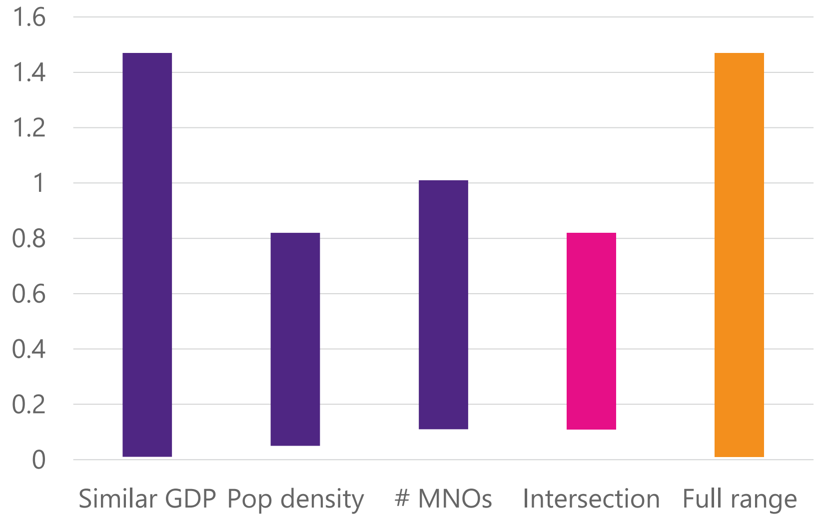
	Group	Sample size	Mean	Min.	1st quart.	Median	3rd quart.	Max.	Range
SPOT	Auctions only	30	0.354	0.019	0.127	0.220	0.356	2.378	0.02 - 2.38
	All awards	43	0.371	0.000	0.108	0.211	0.379	2.378	0 - 2.38
	Similar GDP	16	0.367	0.008	0.102	0.265	0.380	1.474	0.01 - 1.47
	Pop density	8	0.350	0.046	0.112	0.272	0.477	0.816	0.05 - 0.82
	# MNOs	17	0.389	0.112	0.148	0.287	0.501	1.010	0.11 - 1.01
PPP	Auctions only	30	0.545	0.034	0.217	0.427	0.809	1.669	0.03 - 1.67
	All awards	43	0.581	0.000	0.163	0.426	0.820	2.238	0 - 2.24
	Similar GDP	16	0.472	0.009	0.107	0.289	0.452	2.238	0.01 - 2.24
	Pop density	8	0.538	0.034	0.107	0.224	0.696	2.058	0.03 - 2.06
	# MNOs	17	0.542	0.114	0.199	0.372	0.859	1.312	0.11 - 1.31

As can be seen, for some cohorts the sample size was significantly reduced; it is likely that if we had relied on only those observations which matched all three parameters there would have been too few observations to produce a robust result.

With these multiple cohort analyses in place, an overall range can be derived by comparing the individual results. As discussed in our previous report on international benchmarking, the output from this type of exercise tends to take the form of a range of results, depending on the mean, median, standard deviation and quartiles. The range of results from the multiple cohort analysis could be defined as:

- the intersection of all individual ranges, or
- the set including all individual ranges.

Figure 3.3: Use of multiple cohort analyses



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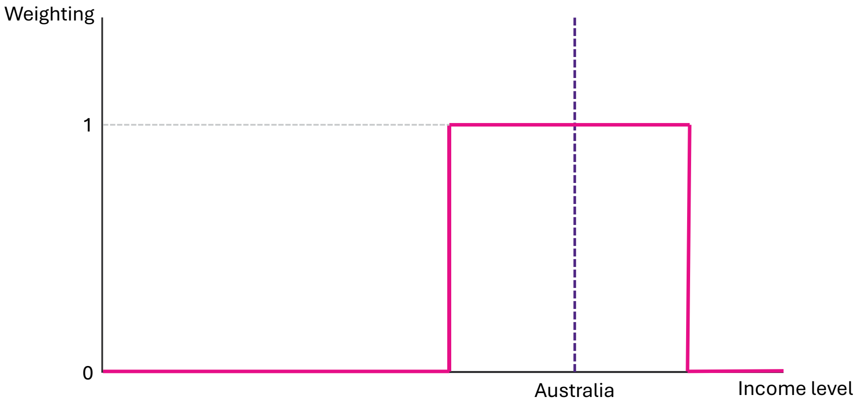
[15] Note that results have been converted to an alternative currency and calculated using a generic WACC to preserve anonymity.

The intersection of analyses is often preferred as it reduces the size of range, excluding outliers in each separate analysis.

3.2 Weightings for country-specific factors

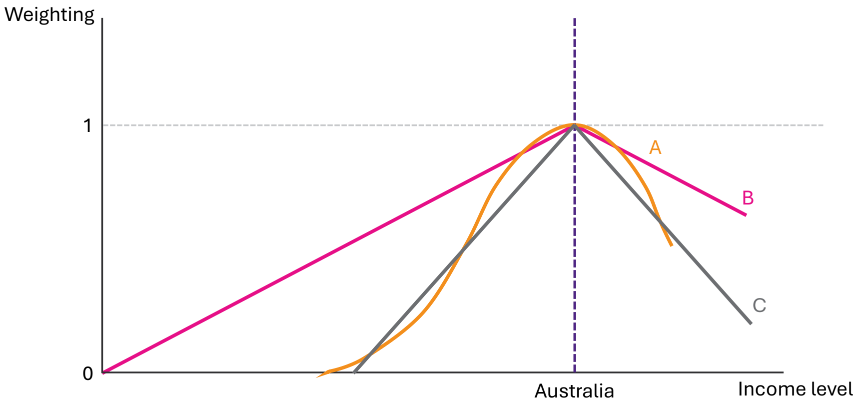
Cohort analysis is, in fact, a special case of applying weightings to observations. Under cohort analysis, an observation is given a weighting of 1 if it is to be included, and 0 if it is to be excluded. Such a weighting is illustrated below, considering income levels. Note that since Australia is a high-income country, then a larger number of countries are excluded below the income level than above.

Figure 3.4: Weighting profile for cohort analysis



Instead of a binary switch, it is possible instead to use a different weighting profile, which gives greater prominence to observations which are similar to Australia but also includes information from countries which are less similar. The shape of this weighting profile can differ considerably; some examples are shown below.

Figure 3.5: Various weighting profiles



In Figure 3.5, the simplest weighting profile to define is illustrated by the magenta line labelled as B. This is a straight line which is 1 at the same income level as Australia, and 0 at zero income (we can assume that this is measured in terms of GDP per capita). For countries below the income level of Australia, the weighting can be easily calculated as the ratio of the comparator country's income to Australia's. So, if GDP per capita in Australia were AUD 100,000, and in Bahrain the corresponding value was AUD 45,000, then a weighting of 0.45 would be applied to any observations of spectrum value in Bahrain.

For countries above the Australian income level, the weighting profile would need to be mirrored – so the difference between the comparator and Australia would be removed from the weighting. Qatar, for example, has a GDP per capita of approximately AUD 130,000; this would then have a weighting of 0.70.

While the weighting profile B does include all comparator countries, it could be considered that countries with a significantly different income level should be excluded. It is unlikely that spectrum values in Syria or the Central African Republic, both of which have GDP per capita of approximately AUD 600, will be relevant. The weighting profile C determines that any countries with income below or above defined thresholds should have a weighting of zero, while observations within this range are linearly scaled.

Rather than a linear profile, it may be decided that any countries with very similar incomes should have a weighting of approximately 1, with a sharper decline at a value further removed. The weighting profile A shows a smoothed curve which can be used for such a purpose. This type of curve can be estimated using an S-curve equation of the form:

$$S(x) = \left(\frac{1}{1+e^{-kx}}\right)^{a}$$

Where k and a define the shape of the curve. Again, the curve must be mirrored to allow for observations above the Australian value for the parameter.

One final consideration is the symmetry of analysis. In the examples above, it is assumed that adjustments above and below the central value should be weighted in the same way – so, for example, countries with incomes of AUD 50,000 and AUD 150,000 would both have a weighting of 0.50. However, it would be preferable to have this analysis carried out on a logarithmic scale, so that, for example, a country with half the income level would be treated the same as a country with double the income level. This would then mean that the weightings would be proportionally the same both ways.

3.2.1 Choice of weighting profile

Given the number of observations included in analysis, and the similarity of most countries which award spectrum at auction, the choice of the weighting profile is unlikely to have a significant impact on the outcome of the valuation, other than the extent to which outliers are included. Certainly, the choice between A and C in Figure 3.5 would likely give little difference in value (while A would be significantly more difficult to calculate).

There has been no academic research carried out on this topic in telecommunications, and there is scarce research in other fields. Muhsen et al (2024)[16] considered the application of weights in benchmarking different environmental factors in the oil industry, settling on a linear relationship, but the application of these weights was more to allow for multiple parameters to be included in analysis. Sarkis & Talluri (2004)[17] used weightings to define clusters of airports in order to carry out efficiency benchmarking. The majority of academic work has considered how different parameters should be weighted together to give predicted outcomes, rather than considering the weighting of observations in a benchmarking analysis directly.

Given this, our recommendation is that analysis should be carried out using a number of different weighting profiles, to understand the impact of these on results. Compared to cohort analysis, the main differences will be in the treatment of observations towards the edges of the cohort definition, who may see themselves with a

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[16] Muhsen YR, Zubaidi SL, Husin NA, Alnoor A, Božanić D & Hashim KS, 2024, "The weight fuzzy judgment method for the benchmarking sustainability of oil companies", Applied Soft Computing, Volume 161, August 2024

[17] Sarkis J & Talluri S, 2004, "Performance based clustering for benchmarking of US airports", Transportation Research Part A: Policy and Practice, Volume 38, Issue 5, June 2004

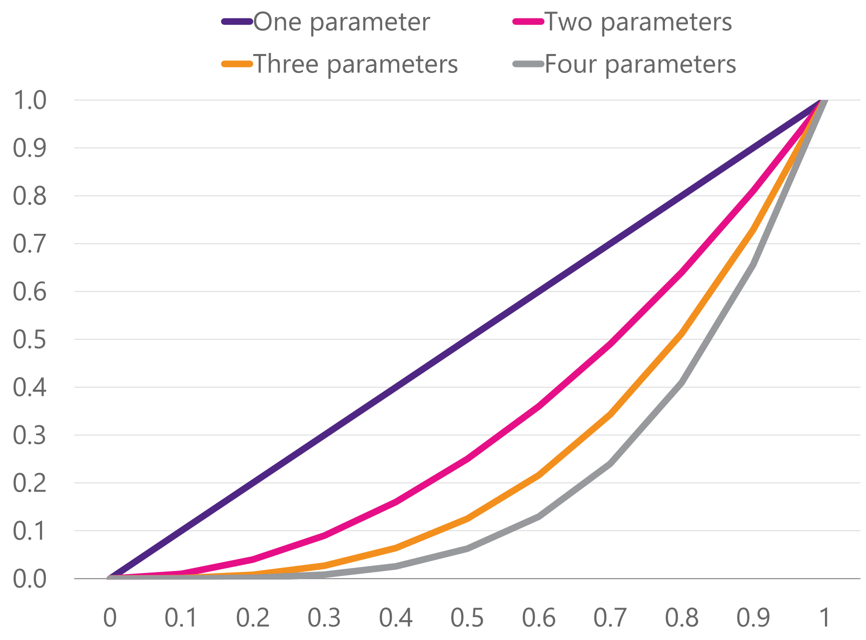
weighting of 0.5 instead of 1 or 0; the actual impact on results will depend on the spectrum values in those countries.

3.2.2 Multiple parameters in weighted benchmarking

Unlike cohort analysis, the application of weights to observations does not reduce the comparator base. It is therefore possible to run multiple parameter weightings at the same time to produce a single output.

In the simplest case this can be done by multiplying the weights together. A country with a weight of 0.8 for income, 0.75 for population density, and 0.6 for market structure would have an overall weight applied of $0.8 \times 0.75 \times 0.6 = 0.36$. As can be seen, this is a relatively small weight despite the fact that on each individual parameter the country is a fairly close match. As shown in Figure 3.6 this can heavily influence the distribution of weights towards the most similar countries, the more parameters are included.

Figure 3.6: Impacts of multiple parameters on weight distributions



It is preferable, therefore, to normalise these weights, possibly by reversing them through the transformation illustrated in the figure above. An overall weight of 0.36 for three parameters would equate to a normalised total weight of approximately 0.71[18]. This calculation results in the geometric mean of the observations.

An easier method, to avoid this concentrated distribution at the index point, would be to take a simple average of weights across all parameters. For the country example above, this would give a total weight of 0.72. However, for some countries – particularly those deemed incomparable in one or more parameters – this averaging would award them excessive influence in the calculation. For example, consider a country with weightings of [0.1, 0.8, 0.9]:

- The total weight from multiplication would be 0.072, which would be normalised to approximately 0.40.

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[18] The curves shown are the exponential graphs between 0 and 1 for increasing powers. For three parameters, the curve follows the cubic equation. Therefore, to translate back, the calculation here is $0.36^{1/3}$.

- The total weight from averaging would be 0.60.

A more extreme example would be a country with weightings of [0.0, 0.9, 0.9] – this would have a multiplicative weight of zero, but an average weight of 0.60.

Given this, multiplying and normalising weights would appear to give a better outcome for the application to benchmarking analysis.

3.2.3 Choice of parameters

Throughout this paper we have used three example parameters to determine how observations should be treated: income level; population density; and market structure. These three examples have been chosen because these have been consistently used in our own analysis. However, there are a number of alternative parameters that can be found. As described in our previous paper on spectrum valuation methods, one potential analysis can be carried out using econometrics. This allows a statistical model to determine which parameters have a direct impact on spectrum value, and the size of this impact.

While econometrics can be used directly to estimate spectrum value, the outputs can also be used to determine which parameters can be used in other benchmarking analysis. Figure 3.7 sets out the variables found to be significant in a recent econometric model used by Plum, where the dependent variable was measured in terms of USD/MHz/pop.

Figure 3.7: Explanatory variables included in an example econometric model

Variable	Relationship with spectrum value	Notes
Log of bandwidth sold during the award	Positive (1% significance level)	Coefficient is positive and indicates that larger bandwidth[19] sold at an award will increase spectrum value per MHz.
Log of Licence Duration	Positive (1% significance level)	Coefficient is positive and indicates that longer licence duration will increase spectrum value.
Log of GDP per capita (USD real)	Positive (1% significance level)	As above. Indicates that increase in GDP per capita increases spectrum value.
Log Population density	Positive (10% significance level)	As above, indicates that increase in population density increases spectrum value. The size of the population density coefficient (i.e. the economic significance) of a 1% change in spectrum value is substantially smaller than the coefficients for licence duration, GDP per capita or spectrum stock.
Time trend	Negative (1% significance level)	Coefficient is negative, reflecting a decrease in total value in the past 10 years. Baseline for the analysis is 2014.
Log of Spectrum stock	Negative (no statistical significance)	Coefficient is negative, reflecting that an increased amount of existing spectrum stock lowers expected value of spectrum.
Spectrum band dummies	Varies (varies)	600 MHz is the baseline group in the analysis (so there is no dummy variable included for the band).
Number of operators	Negative (no statistical significance)	Coefficient is negative, reflecting that a higher number of operators in the country lowers expected value of spectrum.

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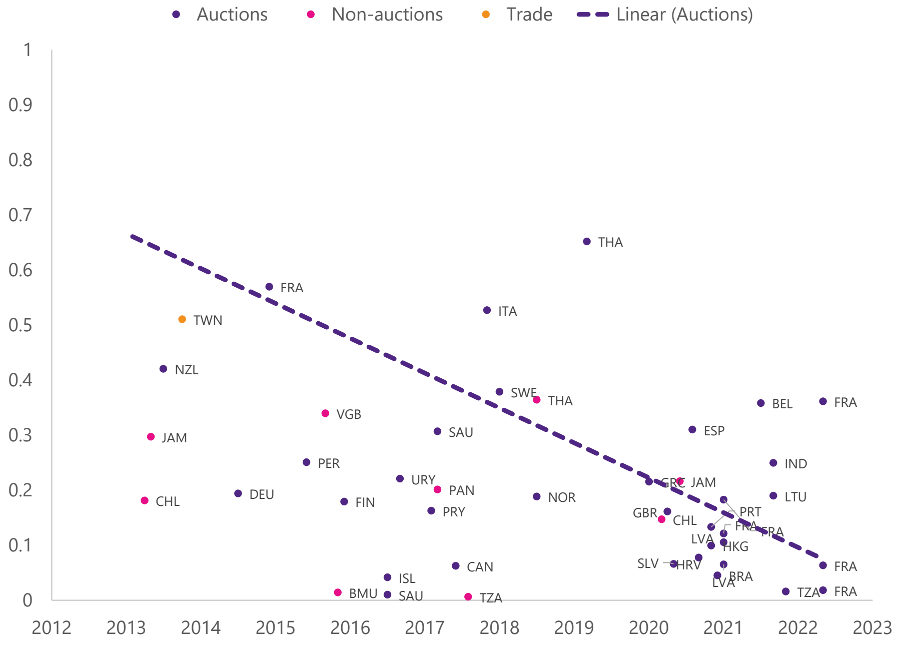
[19] Note that since the analysis included dummy variables for bands, this relationship should be considered only within a single band (and not, for example, comparing the impact of total bandwidth of the 700 MHz band against that of the 26 GHz band.

From this model, it appears that market structure does not impact on spectrum value, and so therefore it should not be included in any weightings[20]. However, other work has shown this to be a valid driver of value. Time trends and the nature of spectrum will be considered below. Other than these, and the parameters already discussed, the main drivers of spectrum value are bandwidth and licence duration, both of which tend to be normalised in the calculation of the dependent variable. We recommend that a separate econometric analysis is carried out to determine relevant parameters.

3.3 Weightings to account for time trends

As mentioned above, there is a significant time trend in spectrum value. Recent analysis carried out by Plum has identified that in almost all bands there is a noticeable downwards time trend, with this trend more pronounced in some bands than others. The two figures below show the overall time trend in 700 MHz and 3500 MHz bands, with all observations labelled.

Figure 3.8: Time trend of real spectrum values (per MHz per pop) in 700 MHz bands



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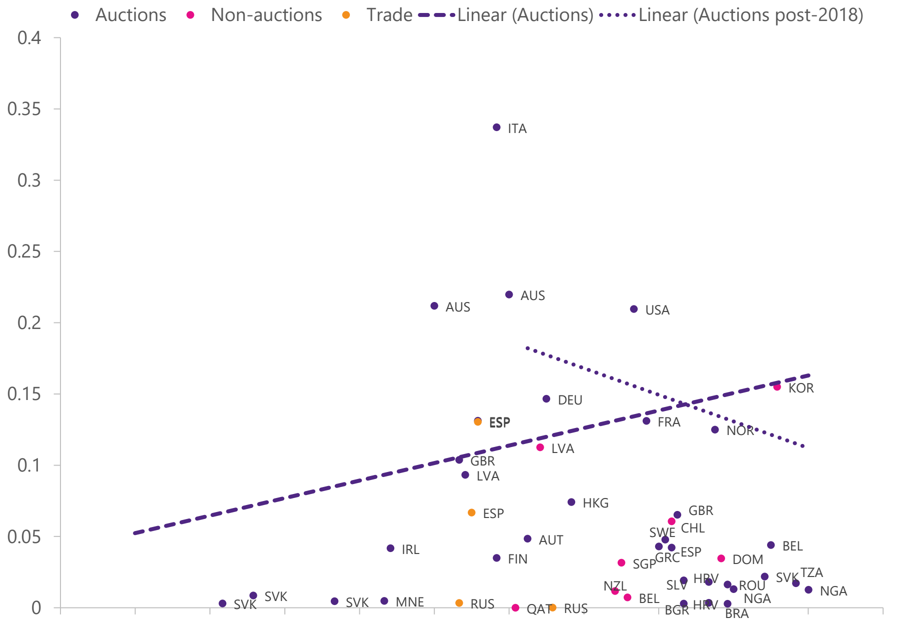
[20] This also raises a separate point. Population density, while having some impact on value, is a less strong driver than GDP per capita. When summing the weightings on individual parameters, should more influence be given to income? That is, should the calculation of the total weighting itself be weighted? While there are arguments for this, operationally is it not plausible to calculate the difference in influence between parameters in order to carry out this analysis.

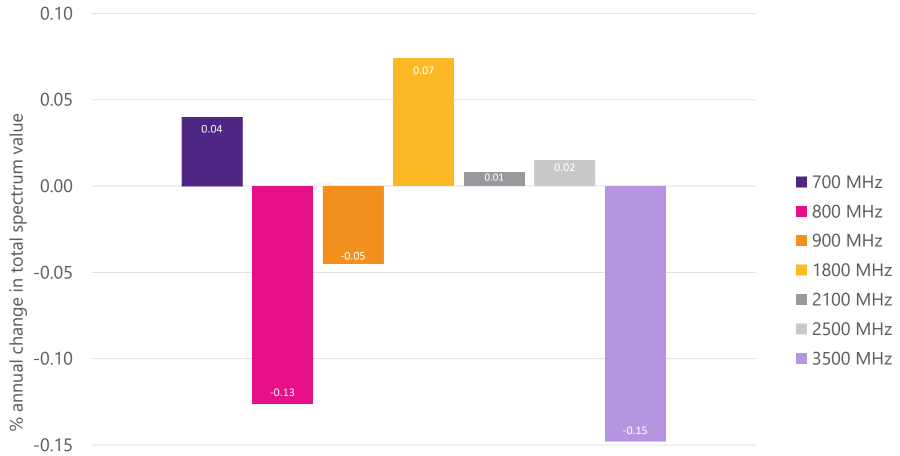
Figure 3.9: Time trend of real spectrum values (per MHz per pop) in 3500 MHz bands



For the 700 MHz band, there is a clear downwards trend over the period. We would not expect this linear trend to continue, as it would imply a zero value for spectrum in the near future, but it is clear that any valuation of spectrum must take the trend into account. For the 3500 MHz band, it appears there is an overall increasing value over time. However, this was largely driven by the fact that in the early years of the analysis the band was largely used for fixed links and satellite communications; since the spectrum band was identified for IMT in 2019 there has been a strong downwards trend.

When looking at the results of econometric analysis, the picture is less clear: a number of spectrum bands have marginal increases over time, although these are not statistically significant in our regressions. This indicates that there is some correlation between another factor and time, meaning that it is difficult to identify the pure time trend.

Figure 3.10: Annual change in total spectrum value (%)



In any case, these trends in value show that care must be taken when trying to use data over a long period to benchmark spectrum value today.

It should be noted that the analysis above has all been carried out on real values, therefore taking into account inflation.

3.4 Other factors driving spectrum value

The ACMA has asked if there are other factors which might impact on spectrum value, which should be taken into account when deriving benchmarks.

As shown in Figure 3.7, our previous econometric analysis has derived a short list of parameters which are found to have a significant impact on value. However, these are not the only factors that are included in our analysis; as part of the econometric modelling process we carry out tests on each variable to determine whether it should be included in the analysis. Some additional variables which were tested but found to be insignificant included the following.

- 5G dummies – set at 1 if the spectrum was due to be used for 5G networks, and 0 if not. We found that spectrum value was not determined by whether it was used for 5G.
- Regional dummies – determining if the spectrum was used in ITU Region 1, 2 or 3. Values are dependent on national differences, not supernational regions.
- ARPU and other revenue or profit indicators – profitability is likely linked to national income, and potential future profitability is a better value driver.
- Competitiveness of auction – other than in the case where there was no excess demand, the number of bidders and number of winners (and ratio thereof) appears to have no impact on the outcome of the auction.

The ACMA has specifically asked if there is a difference in value between foundation spectrum – that is, the first part of any specific band to be awarded – and incremental or additional spectrum. There are relatively few occasions where such awards have taken place, and it is difficult to draw firm conclusions. In many cases (such as in India with the 1800 MHz band in 2012), additional spectrum is awarded where the first auction resulted in unsold spectrum, and therefore the value of the band cannot be directly inferred from the reserve price. In other cases, such as the Australian auction for 3700 MHz spectrum in 2023, additional spectrum has been cleared, and this is sold to complement the existing holdings.

In general, in the second case, we have observed that incremental spectrum attracts a lower price than the original spectrum award. This is likely because it is considered to be less fundamental to running a network, and represents cost savings in capacity rather than increases in coverage. However, this is not universal, and there is no consistent ratio between the values. Incremental spectrum can be much more competitive than original awards, with the relaxation of spectrum caps, or with greater certainty over demand for services, leading to higher values.

It should also be noted that, where there is part of a spectrum band being renewed, even if that was originally the first spectrum awarded, this is in effect the incremental spectrum band (with the other band becoming the foundation). Therefore, where there is a staged process of renewal, depending on the size of the bands awarded, we may observe a permanently lower value of spectrum at renewal point.

4 Adjustments for duration

Although we have considered how spectrum values themselves have changed over time in Section 3.3, there is a more general issue over how the value of money varies depending on duration and time from the present. In particular, to a business the value of money today is greater than the value of money in the future due to increasing uncertainty. When making investment decisions, operators will discount future cash flows to reflect this.

This is important when looking to compare spectrum values between countries; it is also important when seeking to adjust licence terms or set renewal prices. It is useful to consider the value of spectrum in the same way as the value of a tangible asset is treated, with the total capital expenditure being depreciated over time.

4.1 Types of cashflow adjustments

In cost accounting, economic depreciation refers to a depreciation methodology that will result in the book value of an asset at any point in time being equal to the net present value of the cashflow it will generate over the remainder of the asset life. This is an expected outcome of a situation where there is perfect competition in the input (asset) market as well as in the downstream market for the output produced using the input asset.

The economic depreciation approach is commonly proxied by an annuity-based depreciation methodology, which results in the cost recovery of the asset. The depreciation charge and capital charge are computed as a single annual charge. The discounted sum of these annual charges across the life of the asset recovers – that is, it is equal to – the totality of the purchase price and financing costs of the asset (appropriately discounted).

An annuity-based approach to depreciation has an advantage over a straight-line depreciation in that the cost of capital can also be taken into account. A variation of the standard annuity is the tilted annuity. Tilted annuity allows changes in asset price to be taken into account in the calculation of the annuity, and the annuity differs from one year to the next.

Spectrum is considered to be an input asset, which has a useful life corresponding to the spectrum licence duration. There may, however, be a need to readjust the value of spectrum if the licence is not granted for the entire licence duration originally set. This could happen where it is more sensible to align multiple licences' expiry dates. In this case, an adjustment to spectrum value could be made based on a straight-line approach, economic value approach or a tilted-annuity approach.

4.1.1 Straight-line

Straight line depreciation is the most common method of depreciation. It is usually used to reduce the carrying amount of an asset over its useful life. With this method, an asset's cost (purchase price) is depreciated by the same amount for each year. For example, if the asset has a life of L years, the annual depreciation will be a constant value which is equal to (purchase price)/L. A key assumption is that there is no pattern to how the asset is used over time, and so it is reasonable to reduce the value of the asset uniformly over its life.

For a spectrum licence whose duration is L years, its asset life is effectively L. This means that, at the end of m years, where $m<L$, its value will have depreciated by m×(purchase price)/L, under the straight-line depreciation approach. The remaining value of the spectrum asset after year m until the end of the asset life is then (L-m)×(purchase price)/L. The fair purchase value of the spectrum asset, which is only made available for use for m years, is the difference between the original value and the remaining value after year m, and is, therefore, equal to (purchase price) - (L-m)×(purchase price)/L. This equals m/L×(purchase price).

It can be seen above that, under this method, the duration-adjusted value of a spectrum licence is the ratio of the new (shorter) licence duration to the original licence duration multiplied by the purchase price of the spectrum. This is also the total depreciation on the asset after m years.

The use of straight-line depreciation to value an asset at different points in time has one major shortcoming. The remaining value of the asset after depreciation bears no relation to the cashflow-generating (economic) potential of the asset. The asset may yield a relatively low cashflow in the first few years, as demand gradually ramps up, but yield a much higher cashflow towards the end of the asset life, as demand increases to the asset's productive capacity. This means the economic value of the asset in each year changes over time. By reducing the value of the asset at a constant rate, the straight-line depreciation approach does not accurately reflect the remaining economic value of the asset.

4.1.2 Economic value adjustments

An asset which is used to generate a series of cashflows over its life is more accurately valued based on its cashflow-generating potential. Economic depreciation represents such a method for depreciation. The written-down value of an asset at any point in time is calculated as the net present value of the series of cashflows it will generate over the remainder of the asset life. If demand gradually increases in the first few years but rises more quickly thereafter, the depreciation in the first few years will be small to reflect the increase in size of cashflows later on.

Under the economic depreciation approach, the remaining value of a spectrum asset (with a licence duration of L years) at the end of year m (for m<L) is the net present value of the cashflows after year m until the end of year L. The total depreciation at the end of year m is, therefore, the difference between the purchase price of the spectrum (valued for L years) and this remaining value (i.e. the net present value of the cashflows after year m until the end of year L).

By definition, the total net present value of all cashflows from the use of spectrum to the end of year L is the sum of the net present value of all cashflows from year 1 to the end of year m and the net present value of cashflows after year m to the end of year L. Under perfect competition in the input and output markets, this total net present value must equal the purchase price of the spectrum licence.[21] Therefore, the net present value of all cashflows from year 1 to the end of year m equals the total depreciation at the end of year m.

The equivalence between economic depreciation and the truncated value of the spectrum is established above. It follows that the part-period value (for m years) of a spectrum licence can be computed directly as the economic depreciation up to the end of year m. To adjust the spectrum value to reflect a part period up to the end of year m, the ratio of the total depreciation up to the end of year m to the purchase price of the spectrum licence can be used.

In reality, it is unlikely that the exact cashflows needed for this economic value approach can be forecasted accurately. This is the reason that economic depreciation is usually proxied by an annuity, more specifically a tilted annuity. Tilted annuity represents the economic depreciation and capital charge in each year as a single annual charge. This single annual charge takes into account the change in the replacement cost of the asset (at a constant rate), and hence cashflow, over time as well as the financing costs of the asset (cost of capital).

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[21] Otherwise, the spectrum users would be making supernormal profit or loss, and there would be market entry or exit such that the input price changes and only normal profit is made.

4.1.3 Tilted annuity

As previously mentioned, spectrum is an input asset, and so there is an annuity associated with it. In spectrum valuation, the cost (purchase price) of a spectrum licence is the value to be computed, and it will equal the discounted series of cashflows during the life of the asset (licence duration) under perfect competition. The ACMA has provided an example of how such the tilted annuity methodology has been used in adjusting the licence duration in the explanatory statement of the Radiocommunications (Spectrum Access Charges – 1800 MHz Band) Determination 2013 (No. 2)[22]:

> **“The amount set by the Pricing Direction for licences in the 1800 MHz band is $0.23/MHz/Pop, based on a 15-year licence period. However, the licences to which this Determination relates will be re-issued for a shorter duration of 13 years and 45 days, in order to align their expiry date with that of the Tranche 1 re-issued spectrum licences (17 June 2028). Accordingly, in determining the spectrum access charge for the rail authority licences to which this Determination relates, the ACMA assessed the value of the spectrum based on a licence that is re-issued for a period of 13 years and 45 days. The approach essentially first constructs annual cash flows that grow at a constant annual rate across the entire 15 year licence period and are consistent in net present value terms with the then Minister’s valuation ($0.23/MHz/Pop). These constructed cash flows are then re-valued over the shorter licence period.”**

The tilted annuity formula for computing the part-period value of a spectrum licence is given by:[23]

$$PPV_n = \frac{FPV}{\left[1 + \frac{1}{(1+r)^n} \times \left[(1+Z)^n \times \left\{\frac{1 - \left\{\frac{(1+Z)}{(1+r)}\right\}^m}{1 - \left\{\frac{(1+Z)}{(1+r)}\right\}^n}\right\}\right]\right]}$$

Where:

- $PPVn$ denotes the nominal spectrum value of the initial part-period of n years at the beginning of the licence duration;
- FPV denotes the spectrum value over the entire licence duration;
- z denotes the estimated compound growth rate of the cashflow over the entire licence duration;
- n denotes the number of years in the initial part-period, over which the valuation is sought;
- m denotes the number of years in the subsequent part-period; and
- r denotes the appropriate discount rate.

The equation for the tilted annuity formula takes the form, FPV × the adjustment factor:

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[22] Available at https://www.legislation.gov.au/F2013L01995/asmade/text/explanatory-statement

[23] This same formula is, in fact, used in four separate determinations for the 'Tranche 2' 1800 MHz licences with shortened durations. Each determination is based on the same formula and has the same parameters (i.e. same formula, same adjusted duration, same outcome of $0.2106/MHz/pop) in the formula, but each determination is applicable to a different set of licensees. The determination referred to above applies to state rail authorities. Other determinations apply to Telstra and Vodafone.

$$\frac{1}{\left[1+\frac{1}{(1+r)^n}\times\left[(1+Z)^n\times\left\{\frac{1-\left\{\frac{(1+Z)}{(1+r)}\right\}^m}{1-\left\{\frac{(1+Z)}{(1+r)}\right\}^n}\right\}\right]\right]}$$

which is a rearrangement of the formula for $\frac{PPV_n}{PPV_n+PPV_m}$. PPVm represents the nominal value of the remaining period of m years at the beginning of the licence duration, and $PPVn$+PPVm = FPV by definition. Therefore, the adjustment factor computes the proportion of FPV that $PPVn$ makes up, which is consistent with the definition of the quantity (part-period value based on the entire-licence-duration value) that it is being used to compute.

One thing to note is that the adjustment factor is derived using a cashflow series of the form $\sum_{t=1}^{L} A\left(\frac{1+Z}{1+r}\right)^t$, where L is the time period at the end of the entire licence duration. A hypothetical annual cashflow A is assumed for the start of year 1, which grows by z and discounted by r for the first time period (the end of year 1) included in the series of cashflows for licence valuation. In reality, cashflow only starts from the end of year 1, as the business has yet to make use of the spectrum asset to generate cashflow at the start of year 1 when the spectrum licence is first acquired.

A cashflow series with A representing the cashflow at the end of year 1 will have a different form and will result in a different expression for the adjustment factor. A is discounted at the end of year 1 but only starts growing from the end of year 2 in this case. Therefore, a careful application of the tilted annuity formula is needed to ensure that it accurately captures the part-period value to be calculated.

A second point to note is that, although the tilted annuity formula shown above is correct, it could be simplified. The adjustment factor implicit in the formula is a rearrangement of $\frac{PPV_n}{PPV_n+PPV_m}$, following a division of both the numerator and the denominator by $PPVn$. Multiplying $PPVn$ back into both the numerator and denominator of the adjustment factor and rearranging (making use of the fact that $PPVn$+PPVm = FPV) will give a factor of the form $\left\{\frac{1-\left\{\frac{(1+Z)}{(1+r)}\right\}^n}{1-\left\{\frac{(1+Z)}{(1+r)}\right\}^L}\right\}$.[24] This may be simpler to apply as it has fewer terms than the tilted annuity formula above.

4.1.4 Use in benchmark analysis

We believe it is unrealistic to expect that operators or the ACMA will have access to accurate profitability information to construct accurate cashflows for the entire period of a licence period. As discussed in Section 4.1.2, an economic value adjustment would require accurate predictions of profitability for every period during a licence. Therefore, there is no feasible way to make sure of this in benchmark analysis or when calculating duration adjustments.

The straight-line method is computationally simple but does not reflect the reality of cash flows in telecommunications markets. Spectrum bands are often underutilised at the start of a licence period, with increased demand and efficiency leading to greater value at the end[25]. Therefore a duration adjustment using

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[24] This expression of the adjustment factor is, in fact, the ratio of the nominal spectrum value of a period of n years at the beginning of the licence duration to FPV. It is also applicable to an adjustment of licence duration that reflects an extension of the original licence period (i.e. n > L). It is, however, limited to the case where cashflow beyond year L has the same form as the cashflow up to year L (i.e. $A\left(\frac{1+Z}{1+r}\right)^t$).

[25] Note that this is not as much of an issue for spectrum that is being renewed – in this case the spectrum will be utilised on day 1 of the new licence in the same way as it was utilised on the last day of the previous licence. Nevertheless, increased spectrum efficiency and technology changes are likely to change profitability over time.

straight line methods would either overestimate or underestimate the overall value of spectrum depending on which part of the duration was adjusted.

Given this, the tilted annuity method as applied by the ACMA (with a possible adaptation to simplify the calculation) remains best practice; it allows for changing value over time, while being computationally possible. However, if there are large-scale changes in predicted revenues, the annuity estimation may need to be reviewed.

4.2 Types of discount rate

The Weighted Average Cost of Capital (WACC) is the cost of financing typically used by businesses to make investment decisions. It is calculated as the cost of debt and the cost of equity combined, and expressed as a percentage; the WACC is usually an approximation based on a number of assumptions. This percentage is used to discount cash flows for predetermined periods into the future to arrive at a reasonable estimate of the time value of money. The cost of debt may vary based on credit ratings and worthiness, while the cost of equity may vary based on the growth rate and volatility of the industry or sector, as well as the political and socioeconomic factors in the country. Generally, cost of equity is higher than debt, as debt holders are usually compensated first in liquidation; and volatility in equity markets is usually higher than debt markets. Further, the interest expense associated with debt financing is usually tax deductible whereas dividends to shareholders are not.

As can be seen, there are a number of components of WACC which can be assessed in different ways. In particular:

- Should values over time be assessed in real or nominal terms? That is, should an assumption be made over the level of inflation over the period to be investigated, with this included within the discount rate, or should all values be treated as at the current level? In general the correct form of WACC to use here will depend on its application – if the future values have all been adjusted by inflation, in order to bring them back to current values then a real WACC must also be used.

- WACC can be assessed before or after tax is applied (termed as pre-tax or post-tax WACC). Again, this will depend on the regulatory objectives and the information available. The reasons for this include that most profitability analysis is done using pre-tax cash flows and benchmarked against pre-tax cost of capital, introducing bias into the process. Further complicating matters is the effective or marginal rates of taxation for companies, a discussion of which follows below.

- Marginal or effective tax rate. The effective tax rate is defined as General Accepted Accounting Practices (GAAP) taxes, or GAAP pretax income. The marginal tax rate will be the statutory tax rate in the jurisdiction the company operates in. Differences in tax rates usually show up for large MNO's that operate in multiple countries, some with lower tax rates. When the effective tax rate is lower than the statutory tax rate and that difference is likely to be persistent, standard practice is to use the lower tax rate – resulting in a lower tax shield – as the tax rate lowers the cost of debt because it is tax deductible. However, if the effective tax rate is significantly lower than the statutory tax rate but is likely to rise, the tax rate should be adjusted against the cost of debt until it reaches the statutory rate in the terminal year of the tilted annuity.

- As risk varies over time, so too will the applicable WACC. This means that when comparing values at different times it could be possible to apply different WACC values to different benchmarks. Generally the regulator's WACC calculations in the year in question are relied upon, as the risks to the regulator are minimal where annual licence fees are not normally reviewed or not reviewed on the basis of changes in market values. Additionally, it is unusual to have reliable information about the yield to maturity for MNOs' long-term bonds. As such we consider the use of current WACC as practical and proportionate given these considerations.

- Also, as risk changes over time, a WACC that is measured over a long period may differ from a WACC measured at a certain point in time. The difficulties of predictions above apply here as well, with it being unlikely that a value for long-term WACC can be estimated with any degree of certainty.

WACC is not the only the discount rate possible. Others include the following.

- Base Rate (also known as prime lending rate, PLR) is a term for a reference interest rate used by banks. Base Rate is used as a guide for computing interest rates for most of other categories of borrowers which are linked to Base Rate. Annual Base Rate over a period of years – weighted average Base Rate for the years in which Base Rate varied over the course of the year can be applied to calculate the present indexed value.

- Cost Inflation Index (CII) is a measure of inflation that finds application in tax law, when computing long-term capital gains on the sale of assets. The CII can also be used to compute the indexed present value of assets purchased in the past. The year-wise CII can be applied to compute the present indexed value of spectrum previously purchased.

Figure 4.1: Advantages and disadvantages of different discount rates

	WACC	Base Rate	Cost Inflation Index
Advantages	• Reflects comprehensive cost of capital for both debt and equity • Accounts for risk associated with different financing sources • Provides a quick and easy reference point for decision making	• Functions as a standardized benchmark for the risk free rate and is widely recognized • Can be adjusted to reflect current economic conditions	• Accounts for inflationary effects by adjusting cost basis over time • Method is standardized and analysis is more consistent and reliable
Disadvantages	• Sensitivity to market conditions, such as debt costs, equity market fluctuations, and tax regimes • Assumption of constant capital structure over time may not be realistic	• Sensitive to central bank policy shifts • May not reflect industry-specific risks • No consideration of capital structure	• High and unstable inflation may complicate valuations and impair reliability • As a measure of inflation, it may be imperfect due to inherent uncertainty and volatility • Complex and burdensome, requiring continuous monitoring and adjustments • Indexation may not always align neatly with actual cost changes, leading to possible mismatches and inefficiencies

4.3 Variations in prices due to commencement date

In Australia spectrum licences across a range of bands will expire between June 2028 and October 2032 as shown in Figure 4.2. The ACMA has set an expiring spectrum licence (ESL) framework including a 4-stage consultative process, that is aimed at guiding its assessment of options for use of the spectrum covered by ESLs and facilitate applications for renewal.

Figure 4.2: Overview of ESLs in Australia[26]

Band	Licensees	Use case(s)	Beginning of renewal period	Licence expiry
850 MHz original band	TPG, Telstra	WBB	18 June 2026	17 June 2028
850 MHz downshift licence	Optus	WBB	18 June 2026	17 June 2028
1800 MHz	TPG, Telstra, Optus Railcorp (NSW), VicTrack, Queensland Rail, the Department of Planning, Transport and Infrastructure (SA), the Public Transport Authority of Western Australia	WBB Rail safety communications	18 June 2026	17 June 2028
2.5 GHz	Telstra, Optus	WBB	1 October 2027	30 September 2029
2.5 GHz mid-band gap	ABC, Channel 7, Nine Network, Network 10	ENG	1 October 2027	30 September 2029
700 MHz	TPG, Telstra, Optus	WBB	1 January 2028	31 December 2029
2.3 GHz	NBN, Telstra, Optus	WBB	25 July 2028	24 July 2030
3.4 GHz (including new 3.4 GHz licences)	NBN, Telstra, Optus, TPG	WBB	14 December 2028	13 December 2030
2 GHz	TPG, Telstra, Optus	WBB	12 October 2030	11 October 2032

According to this framework, licensees may only apply for renewal 2 years before expiry, and up until the day the licence is due to expire.[27] For example, licensees in the 3.4 GHz band (NBN, Telstra, Optus and TPG) are able to apply for renewal starting 14 December 2028 as shown in Figure 4.3 below.

Figure 4.3: Timeline for licence renewal in the 3.5 and 2.5 GHz bands

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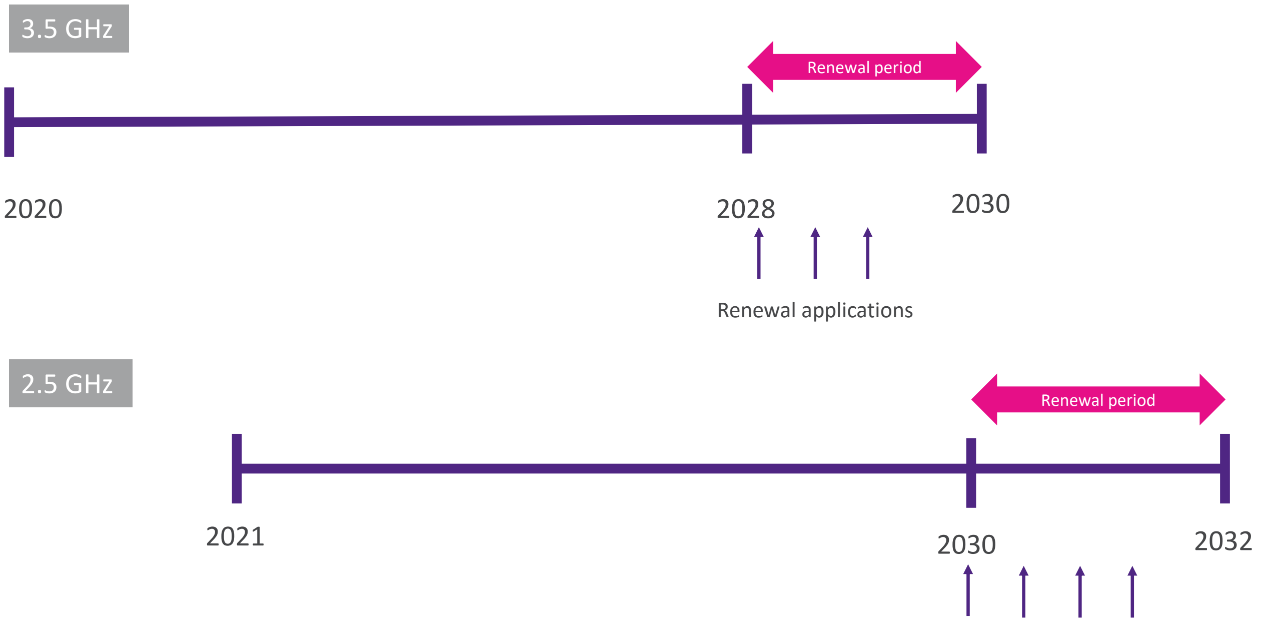
[26] Source: https://www.acma.gov.au/expiring-spectrum-licences - accessed on 28 June 2024

[27] See subsection 77A(3) of the Act



Spectrum pricing is a key consideration for renewal and should be guided by two things:

- **The regulator's spectrum policy objectives:** the ACMA's spectrum policy focuses on the use of spectrum to promote the long-term public interest; and
- **The regulator's licence renewal policy**: there are five potential options, as discussed in Plum's paper commissioned by the ACMA in June 2022[28].

In all cases the licence pricing should reflect the value of the different spectrum bands. However, this value will change over time, depending on how far distance the licence period exists from the date at which the value is considered.

Given the multiple licence expiries over the period from 2028 to 2032, the ACMA is looking to offer operators certainty in terms of the prices that these renewals will be set at, and as such wishes to inform operators in 2025 which price they will be paying at the time of licence renewal. The price for these spectrum licences will differ from the price of a licence commencing in 2025 in two different ways:

- First, the value of spectrum itself will differ between a 20-year licence staring in 2025 and a 20-year licence staring in 2028, due to differences in predicted cashflows, revenues, and technologies. The 5G network is still in its growth phase in Australia and so spectrum used by 5G may become more useful over time, so may be more valuable from 2028. Against this, however, increasing efficiencies, spectrum availability, and technology substitutability means that observed values of spectrum in most bands are falling (see Section 3.3), and so the value of spectrum for a period of 2028-2048 may be lower than the value of spectrum for 2025-2045.
- Second, inflation must be taken into account; operators paying for spectrum in 2028 should consider that any estimation will be in real terms only, and so the nominal value in 2028 will need to be adjusted for an expected inflation rate between 2025 and 2028.

These will be examined in turn, but first we set out some scenarios which will inform our analysis.

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[28] Plum 2022, "International best practice in spectrum licence renewals"

4.3.1 Scenarios for calculating renewal prices

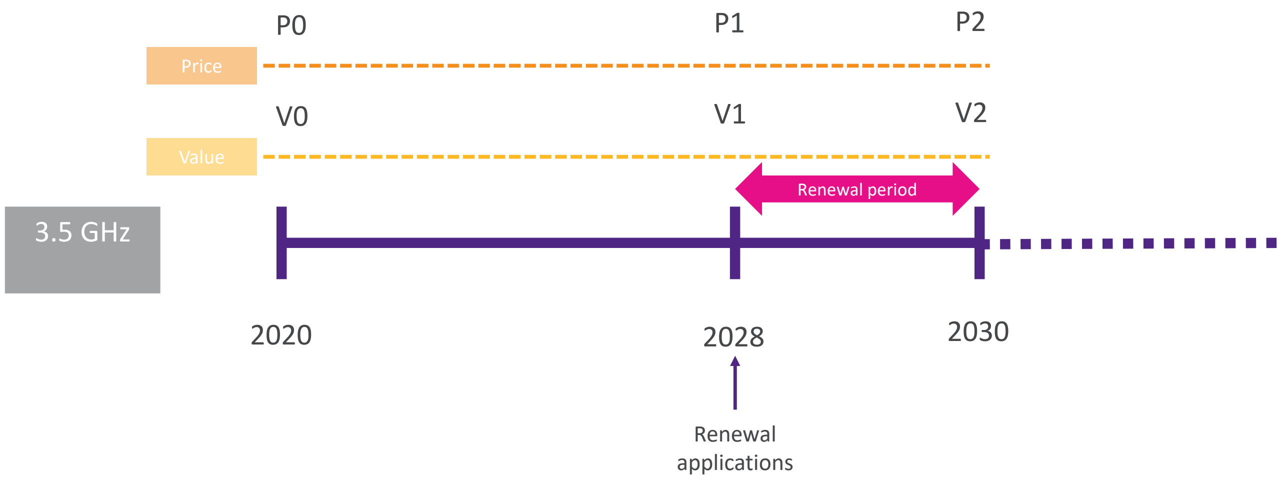
To consider how the timing of the new licence commencement date should be reflected in the price, we consider the following scenarios.

Scenario 1

Licences in the 3.5 GHz band were issued in 2020 and operators paid a price (P0) based on a spectrum value (V0). These licences are expected to expire on 13 December 2030 and the renewal period starts two years before, so on 14 December 2028.

Assuming the ACMA is considering a full renewal, all licensees apply for renewal in 2028. The ACMA needs to set up a licence fee (P2) for licences that will start in 2030. As stated above, the ACMA wishes to inform spectrum holders of this price in 2025, so that there is certainty as to how much will be paid – but it is assumed for this analysis that the price will not be paid until the new licences start in 2030.

Figure 4.4: Scenario 1



The first option is to set a price (P2) which will be paid in 2030 based on the spectrum value (V2) at the new licence commencement date. While this approach is forward-looking and aims at reflecting future market conditions it can involve a degree of uncertainty and the risk of inaccurate predictions; estimating future spectrum values is a complex endeavour as it requires anticipating future technological advancement, as well as market and policy changes.

The second option is to set a price (P1) in 2028 based on the spectrum value (V1) at the time of renewal application, and then set P2 based on this value through use of a discount rate. This requires conducting a more straightforward and less speculative valuation exercise to determine the current value of spectrum. It reflects the current value based on existing market conditions, technology, and policy environment. However, it does not allow the ACMA to inform operators of a firm price in 2025, as required.

The third option is to set a price (P2) to be paid in 2030 based on the spectrum value (V0) at the time of the initial licence issue. This approach provides simplicity as it avoids the complexities of current and future valuations and ensures consistency with the original pricing framework, providing predictability for operators. However, V0 may be outdated by 2030 not reflecting changes in market conditions and leading to potential mispricing of spectrum. In addition, operators may not be incentivized to maximize the efficient use of the spectrum if the price does not reflect its current or future value.

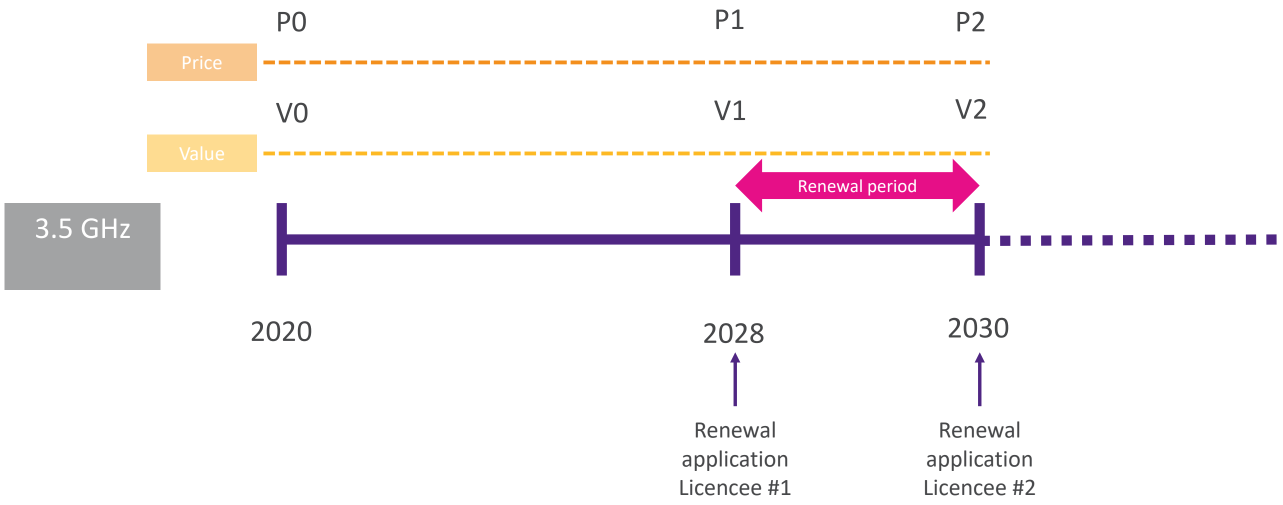
Of these three options, the second would appear to be most realistic, but this does not fulfil the ACMA's desire to inform operators of the price that will be applicable multiple years in advance. Further, care must be taken to understand that the value V1 should be applied to a licence starting two years later, so the value must be appropriately discounted. In order to be able to define prices in advance, the first option will be the optimum, although this will require a detailed consideration of how to model spectrum value in the future. This will be discussed in Section 4.3.2.

Scenario 2

Licences in the 3.5 GHz band have been issued in 2020 and operators have paid a price P0 based on a spectrum value V0. These licences are expected to expire on 13 December 2030 and the renewal period starts two years before, so on 13 December 2028.

Assuming the ACMA is considering a full renewal, Licensee #1 applies for renewal in 2028 while Licensee #2 applies for renewal in 2030 (a few weeks before licence expiry). Licensees wish to pay for their licences at the time of application, not the time of licence renewal. The ACMA therefore needs to set up a licence fee (P1) in 2028 and licence fee (P2) in 2030 for licences that will both start in 2030.

Figure 4.5: Scenario 2



The first option is to set a price (P1) in 2028 based on (V1) and a price (P2) based on (V2) – prices are different. By basing prices on current values at the time or renewal application, the risk of mispricing due to outdated information or incorrect forecasts is minimised and each price will reflect the current market conditions and technological advancements. However, different prices could raise concerns about fairness and consistency as operators renewing at different times will face different costs – even if the present value of these costs is actually the same. As well as this, there is a need to conduct separate valuation exercises each time a licensee applies for renewal which increases administrative workload and complexity.

The second option is to set a price (P1) in 2028 based on (V2) and price (P2) based on (V2) – prices are the same. This approach ensures that both Licensee #1 and Licensee #2 pay the same price for the same licence period (assuming licence conditions are the same), promoting fairness and equity among operators. In addition only one valuation exercise is needed to identify the value of spectrum in 2030, simplifying the administrative process and reducing costs. However, Licensee #1 is financially worse off in this scenario as it has not had access to the cash used to pay for the spectrum during the two year period before the renewal.

It should be noted that while plausible, this scenario is rather unlikely for the following reasons:

- Applying close to the expiry date increases the risk of non-renewal due to unforeseen regulatory or administrative issues. Early application mitigates this risk by providing ample time to address any concerns or requirements from the regulator.
- Operators need to ensure uninterrupted service to their customers. Applying close to the expiry date risks operational continuity if there are delays or complications in the renewal process.
- Operators engage in long-term strategic planning, including spectrum management, network expansion, and investment decisions. Early renewal provides certainty, allowing for better planning.
- Securing spectrum licences early can be a competitive advantage. It allows operators to plan and implement network improvements and service expansions ahead of competitors who might delay.

Alternative option

In the scenarios above the prices have generally been set at P2, when the spectrum renewal occurred, rather than when the spectrum was applied for, and the payment is due at the time of renewal. This would maximise the financial payment to the ACMA while not affecting the values paid by operators. Since operators will want to know the price of spectrum when making investment decisions, the ACMA would need to clearly set out the calculations to be carried out, including the discount rate to be applied.

However, it may be (as discussed in Scenario 2) that operators wish to pay earlier if there is an appropriate discount offered. The two-year period between the start of the renewal application period and the date of the renewal has to be allowed for in this instance, with uncertainty and risk necessarily discounting the price to be paid in advance.

4.3.2 Estimating the value of spectrum in the future

The first option in Scenario 1 above is likely to be the most accurate and robust method for the ACMA to use – estimating a specific value for spectrum over the exact future period of its licence. However, as mentioned this can be a difficult calculation due to uncertainty in the market over extended periods.

There are two methods that we have used in the past to estimate future values of spectrum licences:

- Adjustments through a tilted annuity type method; and
- Application of spectrum value time trends.

These are considered separately below.

Adjustments through a tilted annuity type method

One approach is to consider the series of cashflows implicit in the annuity formula of the spectrum licence value.

Let V = the value in AUD/MHz/pop computed for a spectrum licence starting in year 2025 with a duration of L years, which is calculated based on a benchmarking analysis. If we assume that this is equivalent to the NPV of the series of cashflows between 2025 and year 2025+L, in which the cashflow grows at a constant rate Z, and the annual discount rate (WACC) is r, V can be written as:

$$\sum_{t=1}^{L} A_{2025}\left(\frac{1+Z}{1+r}\right)^{t} \qquad (1)$$

Where A_{2025} is the hypothetical cashflow at the start of 2025 from which the subsequent cashflows during the licence period grow.

If it is expected or assumed that the cashflow will continue to grow in this way beyond year 2025+L, the series of cashflows between year 2025+p and year 2025+p+L can also be similarly expressed as:

$$\sum_{t=1}^{L} A_{2025+p}\left(\frac{1+Z}{1+r}\right)^{t}$$

It should be noted that each term in the series is appropriately discounted to the present (2025), and so the series is the present value of the cashflows from year 2025+p to year 2025+p+L.

However, this series of cashflows also represents the value of the spectrum licence starting in year 2025+p with a duration of L years. Let this be V_1. This means that:

$$\frac{V_1}{V} = \frac{\sum_{t=1}^{L} A_{2025+p}\left(\frac{1+Z}{1+r}\right)^{t}}{\sum_{t=1}^{L} A_{2025}\left(\frac{1+Z}{1+r}\right)^{t}}$$

or

$$\frac{V_1}{V} = \frac{A_{2025+p}\sum_{t=1}^{L}\left(\frac{1+Z}{1+r}\right)^{t}}{A_{2025}\sum_{t=1}^{L}\left(\frac{1+Z}{1+r}\right)^{t}}$$

Because A_{2025+p} is the p^{th} term of the series in (1),

$$A_{2025+p} = A_{2025} \times \left(\frac{1+Z}{1+r}\right)^{p}$$

Therefore,

$$\frac{V_1}{V} = \frac{A_{2025}\left(\frac{1+Z}{1+r}\right)^{p}}{A_{2025}}$$

And

$$V_1 = V \times \left(\frac{1+Z}{1+r}\right)^{p}$$

This enables the value of a spectrum licence with a future date to be estimated from the current value of the spectrum licence. The adjustment factor takes into account the growth of future cashflow relative to the discount rate.[29] Note that all values here will be in terms of the present value of currency, and adjustments will need to be made for inflation if setting prices to be paid at a future time; this will be discussed in Section 4.3.3.

Application of spectrum value time trends

An alternative method is through the application of time trends in spectrum value benchmarks. This is generally associated with an econometric model.

An econometric model allows to estimate the relationships between a dependent variable (the variable of interest, in this case the spectrum price) and one or more independent or explanatory variables. The model fits a best-fit trendline, determined by the assumption of the underlying spread (or distribution) of data values, and computes an equation for that trendline. The model will determine the relationship between the dependent variable and each explanatory variable, assessing the strength and direction of each relationship. These relationships can then be used to predict the value of the dependent variable for a given set of inputs.

As described in Section 3.2.3 and 3.3, Plum has undertaken a number of econometric analyses on spectrum value to identify drivers and time trends, and we are aware that the ACMA (and other Australian bodies) have also undertaken this analysis.

To achieve the analysis identified here, we are required to include a time trend variable as an explanatory variable in the regression model. This variable[30] would capture the overall trend or pattern in the dependent variable (spectrum price) over time allowing us to observe whether there is a consistent upward or downward trend. We can then predict a value of spectrum (V2 in the scenarios above) based on the factors specific to the spectrum awarded (such as frequency band, spectrum stock and, more importantly, the year of the new licence award) and the economic and demographic circumstances in the country of study, in this case Australia.

Another approach is to use the estimate of the time trend variable that captures the relationship between spectrum prices and year of award and apply it to the valuation derived for V0 in 2025. This way, there is no reliance on the model's predictive power which depends on how representative the data sample is.

In both cases, the econometric approach is affected by data availability and data quality. Numerous data points (ideally well over 50 observations) are required to obtain robust parameter estimates.

4.3.3 Adjusting for inflation

Once the value of spectrum at the time of renewal is calculated, it is important to note that this will still be in terms of the currency at the point of evaluation – so, in our case, in 2025 AUD. All modelling or benchmarking will have been done at that level as well. Therefore, in order to work out the nominal price that will be paid at the time of renewal, this value must be adjusted by inflation.

The ACMA could choose from two options.

- First, operators could be informed that the price will be set at X+y%, where y% would be the cumulative inflation rate measured over the period from 2025 to the renewal date. Although this does not give

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[29] The adjustment factor also has the same form where we assume that the first term of the series in (1) is A_{2025}/((1+r) rather than A_{2025}(1+Z)/((1+r) – i.e. each term in the series is A_{2025}(1+Z)^(t-1)/((1+r)^t. (This is the case where A_{2025} is the cashflow at the end of 2025 rather than at the beginning of 2025.) This is due to the fact that A_{2025+p} is the cashflow at the end of year p that has yet to be discounted for year p, and so relative to A_{2025}, A_{2025+p} will still be [(1+Z)/(1+r)]^p times greater.

[30] The simplest approach is to include a yearly variable, set as equal to the year (this will have the same gradient as if a baseline year was set, it simply adjusts the constant. A more granular variable (months or quarters) is not particularly useful as the spectrum value does not change that fast. It is possible in estimation to use yearly dummy variables to allow for complex, non-linear relationships, but this would then not allow forecasting or predictions.

certainty over the exact number of AUD that will be paid, it does provide operators with a knowledge over the real value of the spectrum fee.

- Second, the ACMA could estimate the inflation rate over the period between 2025 and the renewal date and set prices in future AUD. This would give certainty to operators, but if inflation were lower than the estimates this would mean the real prices would be higher, and vice versa.

The inflation rate to be applied in each case should be the Australian producer price index (PPI), since spectrum is an input to the mobile network. For the past few years the PPI has been at around 4% per annum, and it is predicted to remain around this level in the short term (with possible reductions towards the end of 2025)[31].

4.4 Payment terms

Licence fees can be paid as an upfront or through instalments through the licence period. These two approaches have both advantages and disadvantages as shown in Figure 4.6 below.

Figure 4.6: Analysis of payment terms

	Upfront payment	Instalment payments
	For the regulator	
Advantages	• **Immediate revenue**: provide a substantial influx of funds that be used for public investments • **Simplicity**: Simplifies administrative processes by avoiding the need of ongoing monitoring and payment collection • **Risk mitigation**: Eliminates the risk of non-payment or future defaults	• **Increased competition**: Lower initial costs can encourage market entry • **Sustained revenue stream**: Provides a steady stream of revenue over time
Disadvantages	• **Economic impact**: large payments can strain operators' finances, leading to reduced investment in network infrastructure	• **Risk of default**: Operators might default on future payments, especially if market conditions change • **Complexity**: requires ongoing monitoring and enforcement, increasing administrative burden and costs
	For operators	
Advantages	• **Financial planning:** Provides cost certainty and allows operators to secure financing based on a known fixed cost • **No ongoing obligation:** Once the payment is made, there are no future financial obligations, freeing up cash flow for operational expenses	• **Cash-flow management:** Spread-out payments allows for more effective cash flow management • **Lower entry barrier:** Makes spectrum acquisition more accessible to smaller operators and new entrants
Disadvantages	• **Capital strain:** Large upfront payments can significantly impact operators' liquidity	• **Ongoing obligation:** creates long-term financial commitments that must be managed, which can be challenging in a volatile market • **Interest and penalties:** Late payments can incur penalties, adding to the overall cost of spectrum

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[31] See, for example, https://tradingeconomics.com/australia/producer-prices

Note that increased competition and lower entry barriers are considered advantageous in a general setting but not necessarily in the context of licence renewals.