Value of the 600 MHz spectrum band

Report for Free TV

Final

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1 Introduction

1. We have been engaged by Free TV to provide our opinion based on our professional training and experience as economists on issues relating to the reallocation of radio spectrum[1] in the 600MHz spectrum band. Free TV has asked CEG to assess the potential value of Australian broadcast spectrum on a $ per MHz per head of population basis ($/MHz/POP). We have been requested that this assessment would include a discussion of the following three questions:

    a. What is the expected willingness to pay from next highest value users of the 600MHz band?

    b. What value has been achieved in comparable markets?

    c. What approach would unlock the greatest value in Australia?

2. The scope of the assessment excludes detailed assessments on specific auction design elements that may be relevant to the above questions.[2]

1.1 Background

3. In Australia, the 600 MHz (617-698 MHz) spectrum band is currently allocated to digital television services and a range of other licenced low interference potential devices (LIPD), which include wireless microphones and barcode readers.

4. The context for the requested assessment is a Media Reform Green Paper released by the Government.[3] The essence of the Green Paper is a proposal for a scheme in which commercial broadcasters could voluntarily release spectrum in the 600MHz band in exchange for some relief in relation to licence fees and potentially content obligations. This would see broadcasters being transferred from a spectrum licence that required them to pay a fee, to a licence for which there were no fee payable.[4]

[1] In this report we use the term spectrum to refer to radio spectrum. We use the term broadcast spectrum to refer to the 600 MHz spectrum band which is currently allocated to digital television services in Australia by the Australian Communications and Management Authority (ACMA).

[2] For example, issues such as the format of any reassignment auction, the reserve price and block design all may have an effect on the value that can be extracted from the reallocation of the 600 MHz spectrum. These factors may have also influenced the price observed in comparable markets. See Koutroumpis, Pantelis and Cave, Martin (2018) Auction design and auction outcomes. *Journal of Regulatory Economics*, 53 (3). pp. 275-297.

[3] Australian Government, *Media Reform Green Paper: Modernising television regulation in Australia*, November 2020

[4] Television broadcasters combined currently pay spectrum licence fees of around $40 million per year. The amount paid by individual broadcasters depends on the location and power of the broadcast

5. The timeline set out in the Green Paper would involve (a) broadcasters electing to release their broadcast spectrum in 2022, (b) an auction of the released spectrum in 2025, and (c) reassignment of the spectrum to occur in 2026 and beyond. As we discuss below, this timing is relevant to assessing the value of the spectrum the Government is likely to realise.

6. Around the world, the roadmap for the future use of the 600 MHz spectrum band is mixed. The 600 MHz spectrum band has been licensed by mobile operators and is being used to deploy 5G mobile services in a small number of jurisdictions, most notably in the United States (US). As is typical, Canada and Mexico with common borders to the US have also allocated the 600 MHz spectrum band to mobile services to avoid interference issues.

7. The 600 MHz spectrum band has been identified for mobile services in a number of Asia-Pacific nations including New Zealand and, as a result of a new WRC-23 agenda item, additional countries may identify this band for mobile services in the future, though the timing of this is uncertain. However, in Hong Kong, use of the 600 MHz spectrum band is restricted to indoor use given the potential interference with broadcast television in mainland China. In Europe, the Radio Spectrum Policy Group (RSPG) of the European Commission (EC) has also provided a long-term strategy for the future of the UHF band, which suggests the band remain available for broadcasting services until at least 2030.[5]

8. In Australia, the ACMA has indicated it will monitor developments in the period 2020-2024.[6] Subsequent to the release of the Green Paper, the ACMA has released a draft of the 2021-2026 five-year spectrum outlook seeking comment on whether the 600 MHz spectrum should be moved to the "initial investigation" stage of spectrum management.[7,8]

9. The ACMA indicated that it may be possible to restack the 600 MHz band that is currently used for digital television in order to free up a contiguous block in the 600

transmitter their signal uses. The spectrum licence fees were substantially increased in 2017, partially offsetting the abolition of the broadcast licence fees (which were in the order of $130 million per year).

5 ACMA, *Five-year spectrum outlook 2020–24: The ACMA's spectrum management work program*, September 2020

6 Ibid.

7 The ACMA outline four stages for spectrum management band planning: monitoring, initial investigation, preliminary replanning, and implementation. Initial investigation stage is described as follows "[t]his stage normally includes initial consideration of whether the new spectrum use/s contributes to maximising the overall public benefit derived from use of the spectrum, along with preliminary assessments on coexistence and other technical considerations." Ibid.

8 ACMA, *Five-year spectrum outlook 2021–26 work program, Consultation draft*, March 2021.

MHz band (second digital dividend).[9] This would mean up to 84 MHz of spectrum would be available for alternative uses.[10]

1.2 Overview of our opinion

10. In this section we provide an overview of our opinion in relation to the three questions posed by Free TV.

11. In summary, if the proposed timeline in the Green Paper is adopted this will likely yield a relatively low willingness to pay for the 600 MHz spectrum band. The price the Government is likely to realise will be in the range of $0.28 – $0.55 / MHz / Pop. This represents a discount of between 52% - 74% to the median price realised for low frequency (sub-1 GHz) spectrum bands in comparable jurisdictions.

12. We estimate that the *potential* revenue from reallocating 84MHz of 600MHz band is $2.42 billion based on prices paid for low frequency spectrum in comparable auctions in other jurisdictions.[11] However, a discount of 52% - 74% implies *likely* revenues between $0.6 billion and $1.2 billion. The primary reason for this discount will be an oversupply of low frequency spectrum for 5G services in Australia should the 600 MHz allocation follow of the 850/900 MHz spectrum reallocation. The timing proposed in the Green Paper will likely lessen competition for the spectrum due to at least one of the three mobile network operators (MNOs) having an excess of low frequency spectrum.[12]

13. The timing of the reallocation is key to unlocking the greatest value from the spectrum band.[13] The greatest value is unlocked when value is maximised both in the spectrum's current use and future use. This can be achieved by creating market-based incentives for an efficient reallocation of spectrum. The US incentive auction could fairly be described as best practice for unlocking the greatest value from

9 ACMA, Five-year spectrum outlook 2020–24, September 2020, p. 36.

10 Australian Government, *Media Reform Green Paper: Modernising television regulation in Australia*, November 2020, p22.

11 This is estimated based on the median price paid in comparable auctions internationally of $1.15/MHz/Pop, which $2.42 billion in total ($1.15*84MHz*25Million population).

12 The participation of only one or two of the three MNOs in the auction will likely lower the amount paid. This is consistent with the findings in the economic literature and our own regression analysis. See Insua, Manuel; Frias, Zoraida; Pérez Martínez, Jorge (2017): Application of multiple regression analysis to the prices of the spectrum in the IMT band, 28th European Regional Conference of the International Telecommunications Society (ITS): "Competition and Regulation in the Information Age", Passau, Germany, 30th July - 2nd August, 2017, International Telecommunications Society (ITS), Calgary.

13 The value of spectrum is maximised when the spectrum is put to its highest value use. In economics, this is consistent with an efficient allocation of spectrum.

spectrum reallocation.[14] Despite this, administrative decisions by Governments and regulators such as the proposal outlined in the Green Paper remain the most common method of spectrum reallocation. We discuss below elements of a market mechanism which could be adopted in Australia to unlock greater value from the reallocation of the 600 MHz spectrum.

1.2.1 Willingness to pay for the broadcast spectrum by the next highest value user

14. The likely next highest value use of the 600 MHz spectrum band is for international mobile telephony (IMT).

15. In the context of mobile network deployment, the 600 MHz spectrum band is a low frequency band which could support coverage for a 5G (or future technology) network deployment, both across wide areas as well as in-building.[15,16] The 600 MHz spectrum band is an economic substitute for other low frequency bands.[17] As such, to assess the likely willingness to pay for 600 MHz spectrum for mobile in Australia, an assessment is needed of the overall demand and supply conditions for low frequency spectrum bands suitable for mobile services. In general, the auctions of low frequency spectrum bands have coincided with the deployment of each generation of mobile network technology.[18] This has meant that there is strong demand for the

14 For a discussion of the implications of the US incentive auction for other jurisdictions see the following article from the designers of the auction, Symons, H. and Milgrom (2018) "Lessons from the US Incentive Auction", Vol 45 Issue 4, InterMEDIA, pp 25-29.

15 The propagation loss of radio waves increases with the frequency of the spectrum. Therefore, lower frequency spectrum has lower propagation loss than higher frequency spectrum and can therefore cover greater distances. Goldsmith (2005) "Wireless Communications", Cambridge University Press, page 42.

16 We understand the bandwidth gains from 5G deployment using low frequency bands are not particularly significant relative to 4G deployments in similarly low bands. The vastly superior bandwidth capability of 5G relative to earlier mobile technologies will be realised through small cell deployment using high frequency spectrum bands such as the 26 GHz spectrum auctioned in April 2021 by the ACMA. Ofcom state "in low frequency bands, 5G NR capacity and peak speed is unlikely to be significantly better than LTE. The main technology contributing to greater capacity in future mobile networks is massive MIMO, which is unlikely to be feasible in low frequency bands (the antennas would be too big/heavy). Consumers may therefore not notice any significant difference in experience between eMBB served over 4G, 5G NR or a combination of the two." Ofcom, Award of the 700 MHz and 3.6-3.8 GHz spectrum bands, Statement, 13 March 2020.

17 Low frequency bands that are suitable for mobile deployment including other sub-1 GHz frequency bands. The 600, 700, 850 and 900 MHz spectrum bands have been assigned to mobile services around the world.

18 The particular low frequency band used for each mobile technology has varied across jurisdictions.

auctioned spectrum, even more so in markets in which there are potential new entrants.[19]

16. The value of the 600 MHz spectrum bands, and the price that is likely to be realised in an auction of the spectrum, will depend on the expected supply and demand conditions for low frequency spectrum at the time the band would likely be deployed.[20] The value of this spectrum, or any economic good for that matter, is determined based on the balance of supply and demand. Goods that are in high demand with limited supply will have greater value than a good with high demand but a high level of supply, other things equal. A high level of supply will reduce the relative scarcity of a good and hence its value.

17. Figure 1-1 illustrates the spectrum holding of low frequency band spectrum of Telstra, Optus and TPG compared to MNOs in OECD countries in our survey. It shows that each Australian operator would have some of the largest low frequency band holdings of the countries surveyed if the 600 MHz were to be reallocated. Even absent the reallocation of the 600 MHz, Telstra and TPG are above the 75th percentile of spectrum holdings and Optus would be between the 25th and 75th percentile, assuming existing holdings, and potentially at the median following the reallocation of the 850/900 MHz spectrum bands.

18. We note that each of the mobile network operators have each indicated nation-wide deployments of 5G is likely to occur prior to 2026.[21] This would necessitate each operator using holdings of existing low frequency band spectrum (likely the 700/850/900 MHz bands) even if this results in an unbalanced distribution of low frequency spectrum.[22] This significantly lowers the probability the 600 MHz spectrum band will be used for a 5G deployment in Australia. We note that MNOs would face materially increased costs in a dual low frequency band deployment of 5G

19 Cramton, P., Kwerel, E., Rosston, G., & Skrzypacz, A. (2011). Using Spectrum Auctions to Enhance Competition in Wireless Services. *The Journal of Law & Economics*, 54(4).

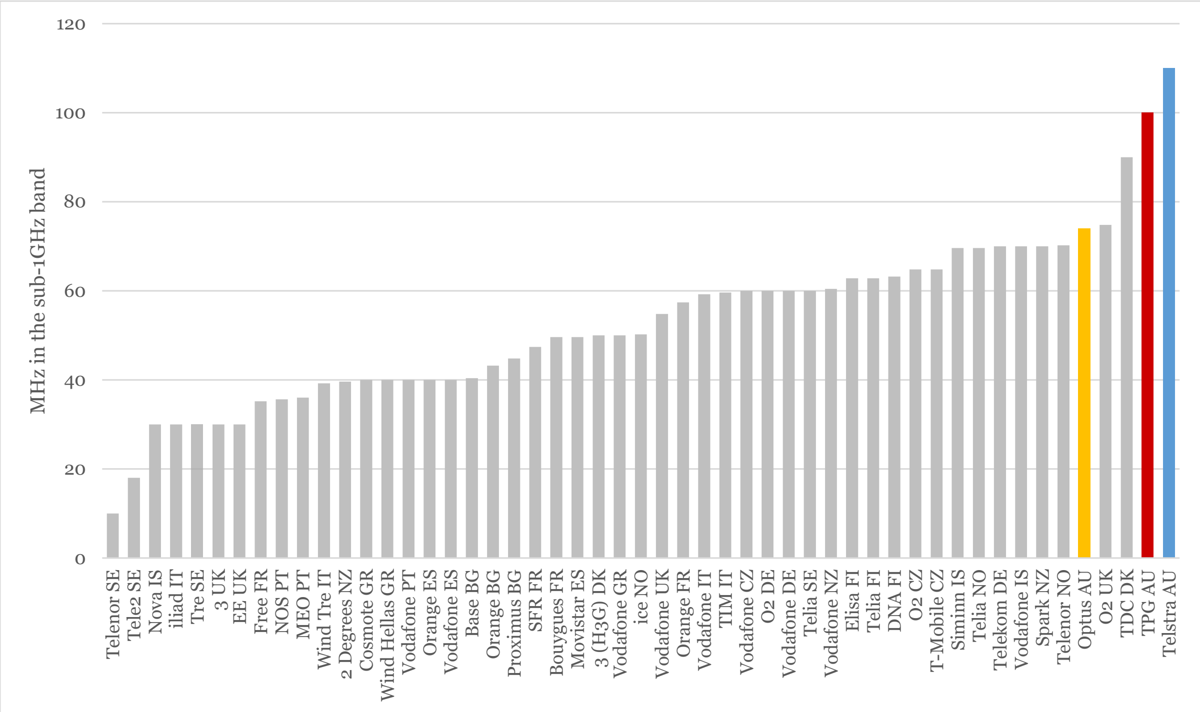
20 In the proposed timeline in the Green Paper, this would mean a 5G deployment post-2026.

21 For example, Optus has indicated that it will deploy its 5G network nationwide in the mid-2020s. https://www.optus.com.au/enterprise/accelerate/technology/a-no-nonsense-guide-to-5g Viewed 28 March 2021. Telstra and TPG have indicated earlier deployments.

22 We noted that issues have been raised with competition limits in the 850/900 MHz spectrum assignment currently being considered by the Government. The Minister for Communications has issued an Exposure Draft of legislation which limits MNOs (or other bidders) ability to bid for the 850/900 MHz spectrum based on their existing holdings of low frequency (sub-1 GHz) spectrum. Our reading of this draft is that it would ensure that no individual MNO is prevented from licensing at least 20 MHz of the 850/900 MHz spectrum due to spectrum being licensed by another existing MNO.

(e.g., there would be material duplication of costs in deploying a single 5G network in both the 600 MHz and 900 MHz spectrum band).[23]

Figure 1-1: Spectrum holding in the sub-1GHz band by mobile operators in Australia relative to the comparable markets



Source: Spectrum Monitoring. CEG analysis. Note: We assume that of the 154 MHz available in the 600 MHz and 850/900 MHz auction, Optus wins 54 MHz while Telstra and TPG each wins 50MHz.

19. In the following two sections we provide two separate estimates of the value impact of the Government reallocating the 600 MHz spectrum as proposed in the Green Paper. In the first section we use regression analysis to estimate the impact of additional supplies of low frequency band spectrum. In the second section we examine the observed value discount from releasing low frequency band spectrum out of sync with the deployment of new mobile technologies.

1.2.1.1 Value impact of an oversupply of spectrum

20. We estimate the value impact of the likely oversupply of low frequency band spectrum should the Government reallocate the 600 MHz spectrum in 2026 by examining the relationship between the prices paid in auctions around the world and the supply of

[23] In addition, post-2026, following the deployment of 5G services it is expected that there will be a shut down of 3G services, resulting in the release of any remaining 900 MHz spectrum to expand 5G capacity using equipment already deployed utilising that band.

spectrum made available in those auctions. We perform a regression analysis on the spectrum prices for the auctions we have surveyed for OECD countries. The regression shows that the price paid for spectrum is lower when there is more spectrum supplied in the auction. It also shows that the price paid is lower when the level of competition[24] in the auction is lower.

21. Our analysis finds that an imbalance between supply and demand will result in a significant difference in spectrum revenue paid in the auction. We estimate that the reallocation of 84 MHz in the 600 MHz band in Australia following the assignment of the 70 MHz in the 850/900 MHz band due in late 2021, will discount the price paid for both spectrum bands by around half. We estimate the joint release of 154 MHz of spectrum for 5G deployment across these bands will likely yield a price of $0.55/MHz/POP. This contrasts with an estimated price of $1.15/MHz/Pop if the 84 MHz of 600 MHz spectrum were assigned on a standalone basis. In terms of total receipts from the 600 MHz spectrum band, we estimate a reduction in receipts from the auction of the 84 MHz from $2.42 billion to $1.16 billion.

22. In summary, our regression analysis estimates that a reallocation timeline as proposed by the Green Paper will result in **a value discount of 52% for both the 600 MHz and 850/900 MHz spectrum bands**.

1.2.1.2 Value impact of an out of sync spectrum reallocation

23. The proposed auction of the current broadcast spectrum based on a reallocation post-2026 would result in a spectrum release that is 'out-of-sync', i.e., one that does not balance the release of spectrum with the spectrum required for the deployment of the next mobile technology. International evidence indicates that this type of out-of-sync auction, will incur **a discount of between 56% and 74% compared to the price paid in in-sync auctions**.

24. When the prices realised in spectrum auctions globally are examined over time, they show a U-shape, with higher prices in periods of the deployment of the next generation of mobile technology and lower prices when the auction is out-of-sync with technology deployment (in the order of 56% lower). This outcome was observed in the case of a German spectrum assignment, where a large quantity of additional low frequency band (700 MHz) spectrum was auctioned at a 74% discount to an earlier low frequency band (800 MHz) auction. It was observed that:[25]

> *The deployment of LTE in the 800MHz band already provides LTE coverage and better in-building penetration. Hence additional 700MHz*

24 We use as our competition metric the ratio of winners to bidders in the auction. A lower value of this metric, more bidders compared to winners, indicates increased competition in the auction.

25 Telecoms, The German spectrum auction: Failure to negotiate? June 2015, https://telecoms.com/opinion/the-german-spectrum-auction-failure-to-negotiate/

spectrum has a lower "coverage value" compared previously acquired 800MHz spectrum.

25. This conclusion is consistent with the fundamental operations of markets being a balancing of supply and demand; and auction successes and failures being driven by imbalances between supply and demand for spectrum. For example, the participation of a new entrant is shown in the academic literature to yield materially higher prices paid.[26] This experience has been observed both in Australia and globally. The auction of the first digital dividend spectrum in Australia did not attract participation by the third mobile operator (Vodafone), leaving 2x15 MHz of spectrum unsold, causing an estimated shortfall of $1 billion in auction proceeds.[27]

26. Similarly in the United States, Verizon did not materially participate in the recent 600 MHz auction as it held sufficient supply of low frequency (700 MHz) band spectrum for its 5G deployment. A higher price would likely have been realised if Verizon bid against T-Mobile in the auction. Also, the recent auction of low frequency band spectrum in the United Kingdom was at a significant discount to equivalent spectrum auctioned in 2013. The significant discount has been attributed to a greater balance of supply and demand than in the previous low frequency auction when there was excess demand.[28]

27. The ACCC has recognised that Optus has a relatively smaller portfolio of low frequency band spectrum than Telstra and TPG. Depending on the outcome of the 850/900 MHz spectrum reassignment, this may leave Optus as the only operator with material interest in the 600 MHz spectrum band.[29,30]

26 ` Cramton, P., Kwerel, E., Rosston, G., & Skrzypacz, A. (2011). Using Spectrum Auctions to Enhance Competition in Wireless Services. *The Journal of Law & Economics*, 54(4).

27 Computer World, Australian government misses $1 billion in Digital Dividend auction, May 2013, https://www.computerworld.com/article/3485709/australian-government-misses-1-billion-in-digital-dividend-auction.html

28 "The auction went smoothly in the end due to what one company representative called "a sweet alignment" between what each network needed to fill out their spectrum position and what was on offer.". Financial Times, 5G spectrum auction raises just £1.3bn for UK government, 17 March 2021, https://www.ft.com/content/41a10fce-4b6a-443d-8c0f-26f62bf2470c

29 ACCC, Allocation limits advice for 850 MHz expansion band and 900 MHz band spectrum allocation, Consultation paper, November 2020.

30 This demand depends on any constraints on Optus' ability to re-farm any 900 MHz spectrum to 5G following a shutdown of its 3G network. We note Telstra plans to shut down its 3G network in 2024. https://www.telstra.com.au/support/mobiles-devices/3g-closure

1.2.2 Values observed in comparable spectrum auctions

28. Radiofrequency spectrum is a scarce resource that is fundamental to the delivery of wireless communications services.[31] Its value can be measured in terms of the cost of lost alternative opportunities from using it (i.e., the opportunity cost). The opportunity cost of using a part of the spectrum is the highest value of that spectrum when put to alternative uses.

29. The primary basis on which we assess the value of the 600 MHz spectrum is by observing the prices paid in comparable spectrum auctions. The prices observed in effective and competitive auction processes should provide a good indication of the market value of the spectrum, with the market clearing price generally being determined by the valuation of the next strongest alternative bidder.

30. We use the prices paid in auctions for spectrum in bands below sub-1 GHz which have been allocated to mobile broadbands services. This includes the 600 MHz, 700 MHz, 850 MHz and 900 MHz spectrum bands. These low frequency bands have similar properties for propagating mobile broadband services,[32] such that they would be considered economic substitutes. In economics, goods and services that are substitutes tend to converge in price.[33]

31. We examine two sources of low frequency spectrum auction results around the world; these include data reported for individual jurisdictions (each of which are OECD member countries) and by the GSMA (which we understand to be from a broader set of countries).

32. We surveyed 28 low frequency band spectrum auctions in comparable markets during the period of 4G expansion after 2010.[34] We found that the median price of these surveyed auctions was **$1.08/MHz/POP** in 2021 dollars, with an interquartile

31 In economic terms, spectrum is a finite, common access, and non-exhaustible resource. This means it is limited supply, it is open to being used by any party, and using it does not reduce its ability to be used in the future. Spectrum supports a range of consumption and production activities.

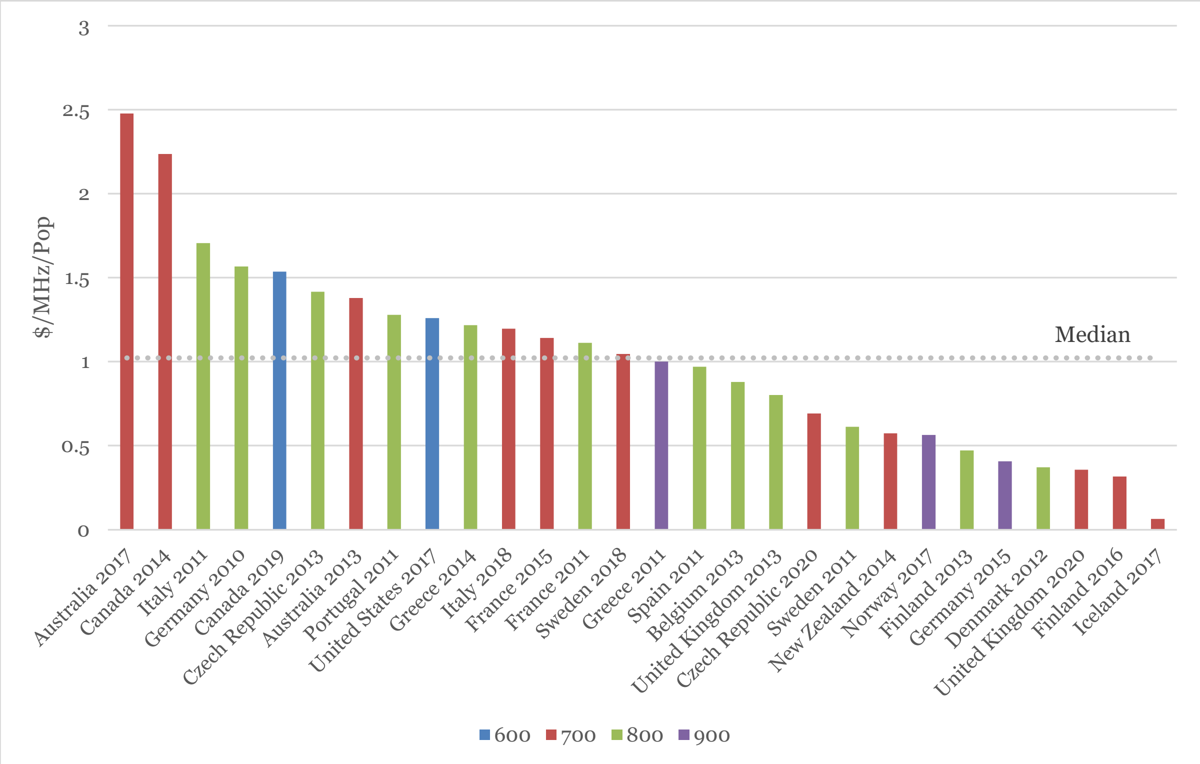
32 Kerans, A., Vo, D., Conder, P. and Krusevac, S., (2011), May. Pricing of spectrum based on physical criteria. In 2011 IEEE International Symposium on Dynamic Spectrum Access Networks (DySPAN) (pp. 223-230). IEEE.

33 Goods that are substitutes tend to converge in price because price differential drive consumers to switch to the cheaper alternative. When goods are perfectly substitutable, and markets are frictionless (e.g., no transaction costs and perfect information), they will have the same price (this is known as the law of one price). Kuksov D. (2016) Law of One Price. In: Augier M., Teece D. (eds) The Palgrave Encyclopedia of Strategic Management. Palgrave Macmillan, London.

34 ACMA, Ofcom, Industry Canada, Radio Spectrum Mgmt NZ, bundesnetzagentur, EETT, Anacom, PTS, FCC, arcep and other regulators, GSMA, Analysys Mason and other media and industry bodies.

range of between $0.6 - $1.43/MHz/POP. The interquartile range captures the bounds of the middle 50% of the prices paid in the markets surveyed.[35]

Figure 1-2: Spectrum auction and prices in 2018 dollars (AU$/MHz/POP)



Source: Telecommunication regulators and media, CEG analysis. Note that the Spain and Portugal auction in 2011 includes both 800MHz and 900MHz bands, the Germany auction in 2015 includes both 700MHz and 900MHz bands, the Iceland auction in 2017 includes both 700Mhz and 800MHz bands. The prices are in 2018 terms. The median in 2021 terms is $1.08/MHz/Pop.

33. We also undertook a regression analysis of the factors that might explain the variation in prices across these auctions. The regression assessed whether the variation in prices could be explained by a number of factors including the GDP per capita in each country,[36] the land area of the country (in million square kilometres), the competitive

35 In other words, the interquartile range is the range excluding the top 25% and bottom 25% of prices paid.

36 Each country's GDP is converted into 2018 Australian dollars as are the prices paid in each auction for consistency in the regression.

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tension in the auction (given by the auction winner-bidder ratio)[37] and the level of supply of spectrum in the auction (in MHz).[38]

34. We find based on this regression that the estimated value of the 600 MHz in Australia if auctioned on a standalone basis would be $1.15/MHz/POP in 2021 dollars. This is above the median of $1.08/MHz/Pop due to the characteristics of Australia (GDP and land area), an assumed equal number of winners/bidders and a standalone auction of the 600 MHz spectrum band. This equates to total receipts of $2.42 billion from 84 MHz of spectrum. For the reasons discussed in the previous section we consider this would be an overestimate of the price that could be realised assuming the timing of the auction and reassignment proposed in the Green Paper.

35. We also examined sub-1 GHz spectrum auction results reported by the GSMA, which indicate a median of $0.81/MHz/POP and interquartile range of $0.80 (1.18-0.38)/MHz/POP. We are unable to confirm whether the reported results by the GSMA are from comparable markets. We note that this is possible given the wide variation in reported prices on /MHz/POP basis. We consider the results of our survey of OECD countries to be more comparable to Australia. Nevertheless, the GSMA figures confirm that we are not understating the results by not considering a broader set of countries.

36. We considered, but do not use alternative approaches which are sometimes used to determine spectrum values, including engineering values from cost models and values reported in secondary trading markets. We explain why below. First, it is not uncommon to value spectrum based on engineering values. These values are calculated based on models that cost the provision of services with and without an increment of spectrum. These models produce an estimate of the value of the additional spectrum to the intended use, which is typically an estimate of the costs savings in providing services from additional spectrum. For example, in the case of mobile networks, additional spectrum can mean cost savings from needing to deploy fewer sites providing services. These savings represent the value of the spectrum in its proposed use. These engineering estimates of value are highly sensitive to the assumptions made by the cost modeller; including assumptions regarding the size and scale of the marginal operator providing services which are subject to some debate. As such, there is a potentially vast range of estimates from such models. For these reasons, we do not rely on the results of such models.

37. Second, in some markets, spectrum can, and is, traded in secondary markets. The price paid in secondary markets is likely to overestimate the opportunity cost of spectrum. This is because the price paid will likely exceed the value of the second

37 Winner-bidder ratio is the ratio of the number of winners versus the number of bidders. For example, if the results of an auction assigned spectrum to two of three bidders in the auction, the winner-bidder ratio was 2/3.

38 Which is the quantity of spectrum assigned in the auction in MHz.

most valuable use. The price agreed in trades would be a split of the differential between the buyer and the seller.[39] As such, we do not rely on these figures for an estimate of the value of the 600 MHz spectrum.

1.2.3 Approach to unlocking the value of the spectrum reallocation

38. The timing of the spectrum reallocation is key to unlocking the highest value of the 600 MHz spectrum band. A reallocation that is "too early", will mean that commercial broadcasters no longer use the spectrum when it is most highly valued in its current use and it will wastefully bring forward expenditures on restacking, whilst the spectrum remains unused by mobile operators. A reallocation that is "too late", will mean that incrementally higher value consumption of mobile broadband services will be delayed when it would be lower cost to restack the commercial broadcasters.

39. The essence of the Green Paper is a scheme in which commercial broadcasters are asked to voluntarily release spectrum in the 600MHz band in exchange for some relief in relation to licence fees and potentially content obligations. The proposal is unlikely to create strong incentives for the efficient release of spectrum relative to the potential value of the spectrum to mobile operators.[40] In contrast to the use of market mechanisms for the reallocation of spectrum, this approach decouples the value payment for the release of spectrum from the value of alternative uses. Linking these payments would have the potential to promote a more efficient allocation and unlock the value of the spectrum. The Green paper proposal therefore represents a continuation of the administrative approach to spectrum reallocation with its well understood drawbacks.[41]

40. The approach outlined in the Green paper can be contrasted with the approach adopted by the Federal Communication Commission (FCC) in the United States for the reallocation of the 600 MHz spectrum band. The FCC used an incentive auction to coordinate the reallocation of the 600 MHz band from broadcasters to mobile network operators. The incentive auction is described by the Noble Prize winning economist who designed the auction in the following terms:[42]

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39 In economic bargaining models, buyers and seller split the gains from trade, being the excess of the buyer's valuation over the seller's valuation. Where buyers and sellers have equal bargaining power, we would expect that the gains were split equally. An equal division was proposed in Nobel Laureate John Nash's seminal paper on bargaining. John Nash, "The Bargaining Problem," Econometrica, 1950. 173.

40 Television broadcasters currently pay around $40 million in spectrum fees annually. This compares to spectrum that could be worth up to $1 billion to mobile operators.

41 Hazlett, Thomas, W. (2008). "Optimal Abolition of FCC Spectrum Allocation." Journal of Economic Perspectives, 22 (1): 103-128.

42 Symons, H. and Milgrom (2018) "Lessons from the US Incentive Auction", Vol 45 Issue 4, InterMEDIA, pp 25-29.

> *A spectrum incentive auction is a market-based means of repurposing spectrum by* ***encouraging licensees to voluntarily relinquish spectrum usage rights in exchange for a share of the proceeds from an auction of new licences to use the repurposed spectrum****. The incentive auction combines a reverse auction, in which incumbents bid to relinquish their spectrum usage rights; a forward auction, in which buyers bid to acquire the relinquished spectrum for new purposes; and a procedure to reconcile the two. [emphasis added]*

41. Allowing commercial broadcasters to share in the proceeds of the auction would create a market-based outcome. Market based outcomes might be preferred to administrative alternatives as they deliver more efficient outcomes, including the amount and timing of the spectrum assignment driven by the relative value of alternative uses rather than administrative fiat or unrelated rewards and penalties.

1.3 About CEG

42. CEG commenced operations in 2007, and is now one of the leading economic consultancies in Australasia and Europe. Since our inception, we have focussed on providing high quality advice to clients. CEG has a reputation for innovative analysis supported by clear theoretical foundations, solid analytics and empirical testing.

43. CEG has offered highly influential expert valuation advice in many regulatory and competition matters throughout the world, in a number of industries, including telecommunications, utilities, mining, petroleum, infrastructure, and intellectual property.

44. CEG is recognised by the Global Competition Review (GCR) as one of the "Top 20" leading economic consultancies in the world advising on regulation and competition issues, with CEG's senior economists regularly recognised in the International Who's Who of Competition Lawyers & Economists and in Euromoney's Guide to Antitrust and Competition experts.

1.4 Structure of this report

45. The remainder of this report is structured as follows:

- Section 2 outlines the economic principles for the valuation of spectrum;
- Section 3 provides background to the issues including: the Green Paper, the current holdings of low frequency band spectrum; and the likely use of the 600 MHz spectrum for 5G deployment in Australia;
- Section 4 analyses the likely effect on auction receipts from reallocating the 600 MHz spectrum given the timing of the release of other low frequency spectrum. It also analyses the discounts that are observed in auctions that are

out-of-sync with mobile technology deployment or have excess supply relative to demand;

- Section 5 provides the results of our survey of international benchmarks of low frequency spectrum values from comparable markets;
- Appendix A surveys some economic literature reference in this report;
- Appendix B discusses the issues relating the upcoming 850/900 MHz spectrum assignment;
- Appendix C covers some technical issues;
- Appendix D provides further detail on the spectrum holdings of the MNOs; and
- Appendix E provides the data sources and further detail on our survey of international benchmarks reported in Section 5.

2 Principles for the valuation of spectrum

46. In this section we discuss the principles relevant to answering the questions posed to us by Free TV in relation to the 600 MHz broadcast spectrum. We first discuss the objectives of spectrum management. We then discuss the economic principles for determining a value of the broadcast spectrum. We conclude this section by discussing the key factors which are likely to drive the value realised in the proposed reallocation of the 600 MHz broadcast spectrum.

2.1 Objectives of spectrum management

47. In economic terms, radio spectrum is a non-excludable, rivalrous good. This means that anyone is able to use radio spectrum (i.e., absent government intervention no party can be stopped/excluded from using spectrum) but the use by one party potentially interferes with the use of others (i.e., there is rivalry in the use of the good). In the absence of government intervention, such goods can face a tragedy of the commons.[43] In an environment where spectrum is scarce, there is a risk that the value of spectrum for uses such as broadcast television, which requires protection from interference, would be lost in a tragedy of the commons, with competing spectrum users unable to resolve the costs they impose on one another. The creation and distribution of private property rights for the use of spectrum creates a 'market system' that generates incentives for spectrum users to maximise the long-term value of the scarce spectrum resource.

48. The main tool adopted by Governments to create a market system for managing spectrum is spectrum licensing.[44] Licensing transforms spectrum from being a common good into a private good with the holder of the spectrum licence having the ability to exclude others from using the spectrum they have acquired. The issuing of spectrum licences is referred to as the assignment of spectrum.

49. The fundamental objective of spectrum management is to contribute to economic welfare and the economic prosperity of Australians. This is best achieved by ensuring that spectrum is allocated to its most productive use and that users have ongoing

43 The concept of the tragedy of the commons was developed in Lloyd, W.F. (1980). W. F. Lloyd on the Checks to Population. *Population and Development Review*, 6(3), 473-496. Recent work by Nobel prize winner Elinor Ostrom has examined local solutions to addressing conflicting uses Ostrom, E. (1990). *Governing the commons: The evolution of institutions for collective action*. Cambridge University Press.

44 Some spectrum bands are not licensed and remain as "common" goods. For example, unlicensed spectrum in the 2.4 GHz spectrum band is used for short range functions such as Wi-Fi and remote controlled devices.

incentives to efficiently use scarce spectrum resources. The creation of spectrum licences which provide for the exclusive use of spectrum is intended to coordinate users of spectrum to the benefit of society.

2.2 Economic principles for valuation

50. When measuring the economic value of broadcast spectrum, it is necessary to first consider the meaning of value in this context. Specifically, economists might distinguish between private value and social value, where the former refers to the net benefits or net cashflows to the holder of the spectrum, while the latter refers to the net private values of all individuals, even those that do not hold the spectrum but who are affected by positive or negative externalities from its use. Spectrum may have broader social value, which benefits citizens from its impact on social goods such as social capital, political freedoms, national culture, security and inequality.[45] This broader social value forms part of the public value of broadcast spectrum and includes elements that are difficult to estimate.

51. In this report we estimate the value of broadcast spectrum in terms of its private value according to the opportunity cost principle, discussed below. This private value will provide an estimate of the proceeds that would be expected from the assignment of spectrum in a well operated auction process.

2.2.1 Opportunity cost

52. Radiofrequency spectrum is a scarce resource that is fundamental to the delivery of wireless communications services. The opportunity cost of using a part of the spectrum is the value of that spectrum when put to the most valuable alternative use. This value therefore represents the lost opportunity that arises from the choice to forego other uses of the spectrum.

53. Achieving the welfare maximising objectives of spectrum management involves ensuring that spectrum is used efficiently. The efficient use of the spectrum involves allocating it to the usage with the highest value. A reassignment of spectrum is efficient when the benefits of the change exceed the costs of the reassignment after taking opportunity costs into account. At a level of economic principle, opportunity cost is the value of something when it is used for a particular purpose. In simple terms, the opportunity cost is the value you must forgo, or give up, in order to use something for a purpose.

45 See for example, report to DCMS, "Incorporating Social Value into Spectrum Allocation Decisions", 2005.

54. Opportunity cost is defined in the value of an asset or resource in the next best alternative that is foregone by virtue of its actual use.[46] The value of an item of is intrinsically related to its scarcity. Things that are more scarce have higher value, other things equal, because there are competing options for the use of that thing:[47]

> *The concept of opportunity cost (or alternative cost) expresses the basic relationship between scarcity and choice. If no object or activity that is valued by anyone is scarce, all demands for all persons and in all periods can be satisfied. There is no need to choose among separately valued options; there is no need for social coordination processes that will effectively determine which demands have priority. In this fantasized setting without scarcity, there are no opportunities or alternatives that are missed, foregone, or sacrificed.*
>
> *Once scarcity is introduced, all demands cannot be met. Unless there are 'natural' constraints that predetermine the allocation of end-objects possessing value (for example, sunshine in Scotland in February), scarcity introduces the necessity of choice, either directly among alternative end-objects or indirectly among institutions or procedural arrangements for social interaction that will, in turn, generate a selection of ultimate end-objects.*
>
> *Choice implies rejected as well as selected alternatives. Opportunity cost is the evaluation placed on the most highly valued of the rejected alternatives or opportunities. It is that value that is given up or sacrificed in order to secure the higher value that selection of the chosen object embodies.*

55. Spectrum is scarce. As such, the allocation of spectrum to one purpose means its use is being denied for another purpose. This is suboptimal from an efficiency perspective if the value of use for the other purpose is greater than the value in its current use. This suboptimal allocation would be harmful both to end users and to the Australian economy more generally.

2.2.2 The allocation and assignment of spectrum

56. There is a long history of administrative decision making in spectrum allocation and in the assignment of spectrum in Australia and around the world. Spectrum allocation is the process of determining the division of spectrum into blocks or bands, the geographic limits for use of the spectrum, and for what process those blocks/bands

46 Buchanan J.M. (1991) Opportunity Cost. In: Eatwell J., Milgate M., Newman P. (eds) *The World of Economics*. The New Palgrave. Palgrave Macmillan, London.

47 Ibid.

are used, or if issued on non-specific use basis what technical and operational rules will apply.

57. Spectrum assignment is the process of determining who gets to access the blocks of spectrum defined in the allocation phase to provide the services they wish. At least as far back as the 1950s, the use of administrative decision making for spectrum allocation and assignment has been criticised and market mechanisms have been proposed.[48] These market mechanisms were aimed at reducing political interference, rent seeking and poor administrative decision making, amongst other things.

58. Market mechanisms are now commonplace in spectrum assignments, but they remain rare for allocating spectrum.

59. It is now common practice that once spectrum has been allocated into blocks for a particular purpose or subject to a set of operational rules that it is then assigned via auction. Regulators have adopted a range of auction mechanisms including simple clock auctions, combinatorial clock auctions and simultaneous multi-round ascending auctions.[49]

60. Spectrum allocation has however remained largely administratively decided. This is in part due to the international coordination of spectrum occurring at the global level, through agreements made at the International Telecommunications Union (ITU), and at the regional level, via the Asia Pacific Telecommunity (APT) of which Australia is a member. These levels of coordination have the objective of harmonising spectrum usage and reducing the costs of service deployment (e.g., by allowing economies of scale in the manufacture of devices that utilise particular spectrum bands). However, this level of coordination involves substantial administrative decision-making. The radio communications division of the ITU, the ITU-R (Radio Communication Sector), holds the World Radiocommunication Conference (WRC) around every three years, where governments negotiate treaties on spectrum allocations.

61. The regionally based process for deciding spectrum allocations has led to a divergence in spectrum allocations around the world. For example, a range of historical, political and technical factors have resulted in divergent approaches to allocating the 700 MHz spectrum.[50]

48 Coase, R. (1959). The Federal Communications Commission. *The Journal of Law & Economics*, 2, 1-40.

49 Lawrence M. Ausubel, Peter Cramton, and Paul Milgrom (2004), The Clock-Proxy Auction: A Practical Combinatorial Auction Design, Reprinted in *Handbook of Spectrum Auction Design*, Martin Bichler and Jacob Goeree (eds), Cambridge University Press, 2017.

50 For a discussion of different approaches to allocating the 700 MHz band, see Mohamed El-Moghazi, Jason Whalley, James Irvine. 2016. The APT Frequency Arrangement in the 700 MHz. ajtde, Vol 4, No 3, Article 56

62. With regard to the 600 MHz spectrum band, consensus was not able to be reached in the WRC in 2015 and some countries were against reviewing the situation in WRC in 2023 because the band is used extensively for broadcasting services: [51]

> *In general, there was a tendency from most of the participants to keep the current situation for the broadcasting service in Region 1 in the band 470-698 MHz and reconsidering the issue in WRC-23 while having the IMT identification in the band in Regions 2 and 3 by footnotes. However, consensus was not possible as* ***even some countries were against reviewing the situation in WRC-23. [emphasis added]***

63. The historical differences in approach to allocating spectrum to mobile broadband around the world has direct implications for the allocation of the 600 MHz band in Australia. Whilst most countries have now allocated the 700 MHz band to mobile broadband, the other spectrum used for mobile broadband differs. For example, the ACMA in Australia has also allocated the 850 MHz and 900 MHz bands to mobile broadband.[52] In contrast, in the US, the 900 MHz spectrum band is not allocated to mobile broadband creating strong demand for the allocation of the 600 MHz spectrum band in the 2017 Incentive Auction.[53,54]

64. The US Incentive auction in 2017 is, to our knowledge, the only example of governments or regulators using a market mechanism for the assignment of spectrum:[55]

> *Auctions have been used by the US Federal Communications Commission (FCC) since 1994 to assign new licences. Before the incentive auction, the FCC simply used its plenary power to relocate the incumbent users from spectrum bands that were licensed via auction. The incumbents were not given any financial incentives to move (other than access to a mechanism for reimbursing them for the costs of moving).*

51 El-Moghazi, A Game of Frequencies at WRC-15: The Future of ITU-R at Stake? https://online.ptc.org/assets/uploads/papers/ptc17/PTC17_Tue_YS2_Paper_El-Moghazi.pdf

52 This spectrum is shortly to be reconfigured and reallocated to mobile broadband.

53 Australia has historically had a higher allocation of spectrum to most other countries including the US, United Kingdom, France, China, Germany, Spain, Japan, Italy and Brazil. See Federal Communications Commission, "The Mobile Broadband Spectrum Challenge: International Comparisons," FCC White Paper, Wireless Telecommunications Bureau, Office of Engineering and Technology, Washington, D.C., February 26, 2013.

54 Details of the Broadcast Incentive Auction can be found at https://www.fcc.gov/about-fcc/fcc-initiatives/incentive-auctions, accessed 20 March 2021.

55 Symons, H. and Milgrom (2018) "Lessons from the US Incentive Auction", Vol 45 Issue 4, InterMEDIA, pp 25-29.

2.2.3 Supply and demand balance will determine value of spectrum

65. The determinants of the price of goods and services in the economy have been explored in writing at least since Adam Smith's invisible hand in the *Wealth of Nations*. It was Alfred Marshall, at the turn of the 20th Century that formalised the concepts of demand and supply in the determination of the prices of goods and services exchanged in a market. Marshall developed the now well understood concept of supply and demand schedules (or curves) with prices settling at an equilibrium at the point where the schedules or curves intersect. Marshall famously noted:[56]

> *We might as reasonably dispute whether it is the upper or the under blade of a pair of scissors that cuts a piece of paper, as whether value is governed by utility or cost of production. It is true that when one blade is held still, and the cutting is effected by moving the other, we may say with careless brevity that the cutting is done by the second; but the statement is not strictly accurate, and is to be excused only so long as it claims to be merely a popular and not a strictly scientific account of what happens*

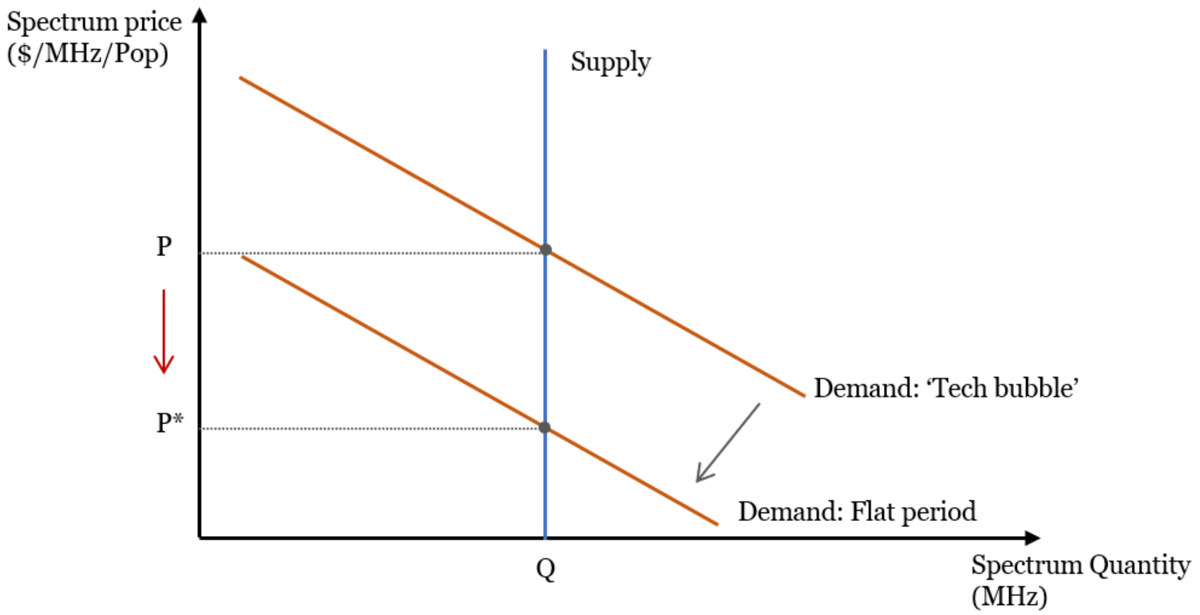
66. These general principles of price setting describe by Marshall apply equally to the price or value determined for spectrum through a market process and can be used to illustrate the effect of changes in supply and demand. We consider two simple illustrations of how changing the balance of supply and demand effects the price, or value, of spectrum.

67. In both illustrations we assume the supply curve is a vertical straight line, which means the price paid by the MNOs will not affect the supply of spectrum from the regulators directly. In the first illustration, we examine a decrease in spectrum demand. A general decrease in spectrum demand may be related to, say, the end of a 'tech bubble'. Alternatively, a decrease in demand for a particular spectrum band (say the 600 MHz spectrum band) may occur because operators can re-farm substitutable spectrum from another band (say the 900 MHz band due to a switch off of 3G mobile services).

68. The decrease in demand means that there are smaller quantities demanded at all prices. This is shown in the following figure by a shift in the demand curve for spectrum to the left resulting in the equilibrium price (or value) falling from P to P*, while the supply level remains constant.

56 Marshall, Alfred, 1842-1924. (1920). *Principles of economics; an introductory volume*. London, Macmillan

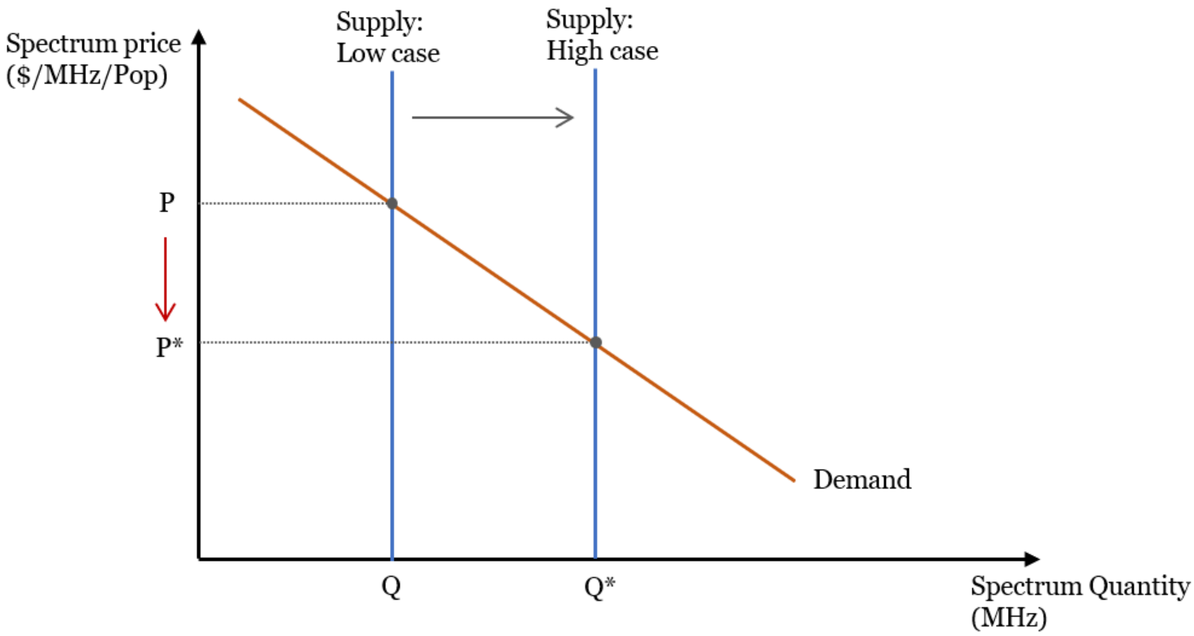
Figure 2-1: Stylised decrease in spectrum demand



Source: CEG analysis

69. In the second illustration, we show an increase in spectrum supply. An increase in supply shows the case where the government offers a larger quantity of spectrum to the market (by reallocating spectrum currently allocated for another purpose). Assuming demand is constant, the equilibrium price paid by operators would decrease as the quantity supplied increases.

Figure 2-2: Stylised increase in spectrum supply



Source: CEG analysis

70. In section 4 of this report, we explore the empirical relationship between the price paid in auctions and supply, or quantity, of spectrum offered in auctions of low frequency band spectrum. We find, as predicted by the theoretical and illustrative analysis above, that the price paid in auctions is lower when there is a greater quantity of spectrum auctioned. This result has implications for the value of the 600 MHz band spectrum. An additional supply of low frequency band spectrum auction shortly after the 850/900 MHz auction will materially reduce the value realised in both auctions. We estimate this reduction to be in the order of $1 billion.

3 Supply and demand for low frequency band spectrum

71. The 600 MHz spectrum band is a low frequency band spectrum well suited to providing coverage for a mobile broadband network deployment providing 5G services. In this section we conclude that given the current spectrum holdings of MNOs, that there is likely to be an excess of supply of low frequency band spectrum for mobile operators within the proposed timing for reallocating the 600 MHz spectrum in the Green Paper.

72. In summary, this conclusion follows from the facts and assumptions below:

   a. The three MNOs (Telstra, Optus and TPG Telecom) are likely to seek to deploy nation-wide 5G networks in the mid 2020 or earlier;[57]

   b. The deployment of a nation-wide 5G mobile network will require each MNO to select a single low frequency band to provide the base coverage network. It is unlikely that an MNO would deploy 5G using multiple low frequency bands (i.e., using a combination of the 600/700/850/900 MHz spectrum bands). This is due to the cost of aggregating low frequency band spectrum. MNOs will therefore likely choose a single base, low frequency band for their respective 5G deployments;

   c. The reconfigured 850 MHz and 900 MHz spectrum bands to be assigned in 2022 are prime candidates for the base frequency for nation-wide 5G deployments by each of the MNOs, though MNOs may alternatively refarm their 700 MHz;[58]

   d. With appropriate competition limits, each of the MNOs will hold sufficient spectrum to deploy 5G with existing spectrum bands;

   e. Additional low frequency spectrum in the 900 MHz band will become available as MNOs switch off their respective 3G networks. Under the proposed arrangements for the 850/900 MHz auction, TPG and Optus can apply for 10 MHz of the 900 MHz spectrum to be set-aside in order for them to continue to provide 3G services; and

   f. The reallocation of the 600 MHz spectrum band to mobile broadband would provide MNOs in Australia with inordinately large holdings of low frequency spectrum relative to operators in comparable markets;

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57 Telstra has indicated a timing of 2024 for the switch off of its 3G network in 2024. https://www.telstra.com.au/support/mobiles-devices/3g-closure

58 Vodafone has trialled 5G services using spectrum in the 700 MHz band and has indicated it may refarm this spectrum. https://r-spectrum.com.au/resources/mobile-network-operators/vodafone-australia Accessed 25 March 2020.

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g. In the less likely scenario that one of the MNOs (say Optus) were to delay its national wide 5G deployment to use 600 MHz spectrum post-2026, it is likely to mean limited competition in acquiring that spectrum (reducing the proceeds from that spectrum).

3.1 Supply of low frequency spectrum

73. In this section we discuss the supply of low frequency spectrum with and without the reallocation of the 600 MHz spectrum band. We compare the holdings of MNOs in Australia with those in comparable markets.

74. The free-to-air broadcasters are allocated UHF spectrum to deliver their digital broadcasts. The original digital dividend process involves clearing free-to-air broadcasters from the 694 MHz – 820 MHz (otherwise known as the 700MHz) band and relocating digital broadcasting to 520 MHz and 694 MHz. The 700 MHz band was reallocated to mobile broadband services.

75. Table 3-1 sets out the current spectrum held by Telstra, Optus and Vodafone/TPG in the 700 MHz, 850 MHz, and 900 MHz bands. Note that the spectrum in the 900 MHz band is all subject to reassignment in late 2021.

Table 3-1: Current spectrum holding (MHz)

	700 MHz	850 MHz	900 MHz (Subject to reallocation)	Total
Telstra	40	20 metro/30 regional	16.8	76.8 metro/86.8 regional
Optus	20	-	16.8	36.8
Vodafone/TPG	30	20 metro/10 regional	16.4	66.4 metro/56.4 regional
Total	90	40	50	180

Source: ACMA and ACCC, CEG analysis. Note: Showing spectrum holding at national level unless specified. Telstra holds 20 MHz in the metro area but 30MHz in the rural area in the 850 MHz band. TPG holds 20MHz in the metro area and 10MHz in the rural area in the 850MHz band. Optus does not hold any spectrum in the 850MHz band.

76. The amount of low frequency band spectrum available to MNOs will be increased in the future due to the reallocation of the 850 MHz and 900 MHz spectrum bands as declared by the Minister for Communications:[59]

   - This includes an expansion of the 850 MHz spectrum band that adds 20 MHz; and

59 Radiocommunications Spectrum Re-allocation—850/900 MHz Band) Declaration 2020.

- A reconfiguration of 50 MHz of the 900 MHz spectrum band from the current arrangement with three licences (two 16.8 MHz for Telstra and Optus and one 16.4 MHz for TPG), to a modified arrangement with five blocks of 10 MHz licences.

77. A second digital dividend of the kind mooted in the Green Paper would free up to 84 MHz of the 600 MHz spectrum band that is currently allocated to digital television.[60]

78. In total, these measures above will free up 154 MHz of low frequency spectrum to be used by MNOs in the coming years, inclusive of the 50MHz in the 900 MHz band reconfigured from the current arrangement.

3.1.1 Low-frequency band spectrum holdings with/without 600 MHz spectrum reallocation

79. In this section we show the spectrum holdings of each MNO in Australia with and without the reallocation of the 600 MHz spectrum.

80. Table 3-2 shows the re-allocated spectrum holdings of the three MNOs under two scenarios for metro area. The first scenario is one in which only the 850/900 MHz spectrum is assigned without reallocating the 600MHz spectrum. The ACMA has proposed that the 900 MHz spectrum will be released as five blocks of 2×5 MHz spectrum along with two 2×5 MHz blocks from the expanded 850 MHz spectrum (70MHz auctioned in total).[61]

81. The results of the reallocation are shown in the second column of Table 3-2 below. We assume that Optus licenses three blocks (30MHz) of the 850/900 MHz spectrum, while Telstra and TPG each license two blocks (20MHz).[62] The total amount of spectrum available to the three MNOs has increased by 20 MHz in total as a result of the expansion of the 850 MHz spectrum band.

82. In this first scenario, we have Optus holding 50 MHz of low frequency spectrum; 20 MHz of 700 MHz spectrum and 30 MHz of 850/900 MHz spectrum. The proposed competition limits for the 850/900 MHz spectrum would restrict each

60 Australian Government, *Media Reform Green Paper: Modernising television regulation in Australia*, November 2020, p22.

61 ACMA, Draft instruments for the 850/900 MHz band auction Consultation paper APRIL 2021

62 We make the assumption based on the fact that "Optus holds significantly less low band spectrum (only 15 per cent of total low-band spectrum available) than Telstra and TPG." ACCC, Allocation limits advice for 850 MHz expansion band and 900 MHz band spectrum allocation Consultation paper, November 2020, https://www.accc.gov.au/system/files/MACE%20-%20850_900%20-%20Allocation%20limits%20advice%20consultation%20paper%20-%2023%20October%202020%20%289%29.pdf

participant to holding no more than 82 MHz of low frequency spectrum.[63] The effect of this is that Optus would not have to compete with Telstra and TPG to acquire at least 20 MHz of the 850/900 MHz spectrum band.

83. The second scenario is based on the reallocation of 600 MHz spectrum band to mobile broadband. If this occurs a further 84 MHz will be added, meaning that there will be in total 154 MHz available for auction.[64] This scenario is shown in the last column of Table 3-2 assuming that Optus wins 54 MHz while Telstra and TPG each win 50MHz, the total amount of spectrum for auction is 154 MHz, of which 70 MHz is from the 850 MHz/900MHz and 84 MHz is from the 600 MHz digital dividend.

Table 3-2: Low frequency spectrum holding under different assumptions (MHz) for metro areas

	Current	Current with 900MHz cleared	Reallocating 850/900 MHz only*	Reallocating both 600MHz and 850/900MHz^
Telstra	76.8	60	80	110
Optus	36.8	20	50	74
TPG Telecom	66.4	50	70	100
Total	180	130	200	284

*Source: ACMA, CEG analysis; For metro area only for Australian carriers. *We assume that of the 70MHz available in the 850/900MHz auction, Optus wins 30 MHz while Telstra and Vodafone/TPG win 20MHz each; ^ We assume that of the 154 MHz available in the auction, Optus acquires 54 MHz while Telstra and TPG each acquires 50MHz.*

84. Table 3-3 shows the re-allocated spectrum holdings of the three MNOs under two scenarios for regional areas. In this first scenario, we assume that of the 70MHz available in the 850/900MHz auction, Optus and Vodafone/TPG each wins 30 MHz, while Telstra will only acquire 10MHz in regional areas. This ensures that the spectrum acquired by Telstra is within the competition limits as proposed by the Minister's Exposure Draft instrument setting the competition limits in response to the recommendation from the ACCC.[65] In the second scenario, we assume that of

63 The proposed limit is 80 MHz. The additional 2 MHz will be used as a guard band between the 824–825 MHz and 869–870 MHz. The primary purpose is to facilitate agreement between the licensees of the lower 900 MHz lot and adjacent 850 MHz band spectrum (frequency ranges 825–845 MHz and 870–890 MHz) to achieve a timely downshift. For simplicity, we use the proposed limit of 80 MHz in our analysis. ACMA, Draft spectrum re-allocation recommendation for the 850/900 MHz band Consultation paper, May 2020.

64 We assume 84 MHz in the 600 MHz band will becoming fully available. If the spectrum is assigned based on 5 MHz blocks, it is possible that only 80 MHz will be assigned.

65 Radiocommunications (Spectrum Licence Limits—850/900 MHz Band) Direction 2021, 27 April 2021, https://www.communications.gov.au/have-your-say/850900-mhz-auction-allocation-limits-exposure-draft

the 154 MHz available in the auction, Optus acquires 54 MHz, Telstra acquires 40MHz and TPG acquires 60MHz in the regional area. Our assumption brings the spectrum holding in regional area consistent with the spectrum holding in the metro area.

Table 3-3: Low frequency spectrum holding under different assumptions (MHz) for regional areas

	Current	Current with 900MHz cleared	Reallocating 850/900 MHz only*	Reallocating both 600MHz and 850/900MHz^
Telstra	86.8	70	80	110
Optus	36.8	20	50	74
TPG Telecom	56.4	40	70	100
Total	180	130	200	284

*Source: ACMA, CEG analysis; For regional area only for Australian carriers. *We assume that of the 70MHz available in the 850/900MHz auction, Optus and Vodafone/TPG wins 30 MHz each, Telstra wins 10MHz; ^ We assume that of the 154 MHz available in the auction, Optus acquires 54 MHz, Telstra acquires 40MHz and TPG acquires 60MHz.*

3.1.2 International comparison of spectrum holdings with Australian MNOs

85. In this section we compare the low frequency band spectrum holdings of MNOs with MNOs in Australia with those in comparable markets with and without the reallocation of the 600 MHz broadcast spectrum. We show that even without the reallocation of the 600 MHz spectrum band, MNOs in Australia have large holdings of low frequency spectrum relative to MNOs in comparable markets. If the 600 MHz spectrum band is allocated to mobile broadband in Australia, MNOs in Australia are likely to have an excess supply of low frequency spectrum when compared to their international counterparts.

86. We have collected the holdings of low-frequency, sub-1 GHz, spectrum held by operators in the 16 OECD countries we have surveyed for our value benchmarking.[66] In total, we have collected information for 51 operators in 16 countries as reported by Spectrum Monitoring.[67,68] The results of the survey show that the median sub-1 GHz

[66] See Section 5 of this Report.

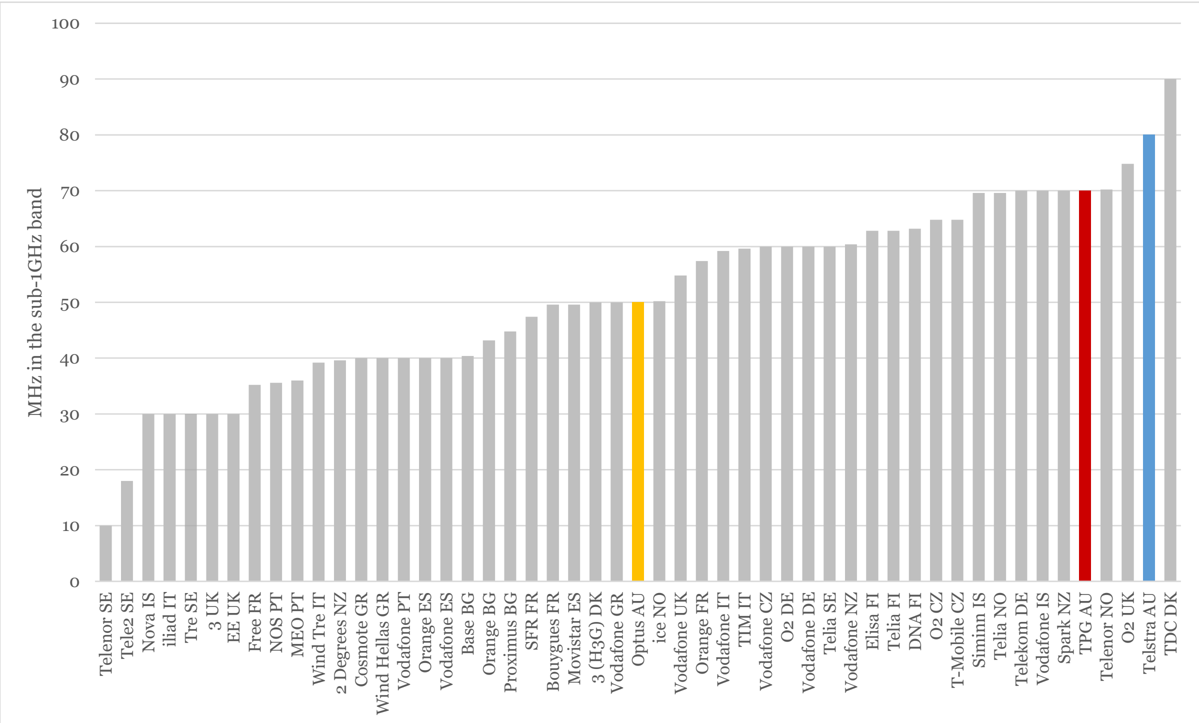
[67] https://www.spectrummonitoring.com/

[68] Note that this data is not available for the United States and Canada as spectrum is awarded on a regional basis in those jurisdictions.

spectrum holding for the 51 operators surveyed is 50 MHz of low frequency spectrum, with the 25th percentile holding at 39.7 MHz and 75th percentile holding at 62.8 MHz.

87. Figure 3-1 below illustrates the comparison of the spectrum holdings of Telstra, Optus and TPG with MNOs in comparable markets.[69] It shows that even without the reallocation of the 600 MHz spectrum band, Telstra (80MHz) and TPG (70MHz) will be higher than the 75th percentile of low frequency spectrum holdings globally. At the same time, the spectrum holding of Optus (50MHz) will be at the median among all the countries surveyed. The full survey is in 207.

Figure 3-1: Spectrum holding in the sub-1 GHz band by operators: without the 600 MHz spectrum reallocation



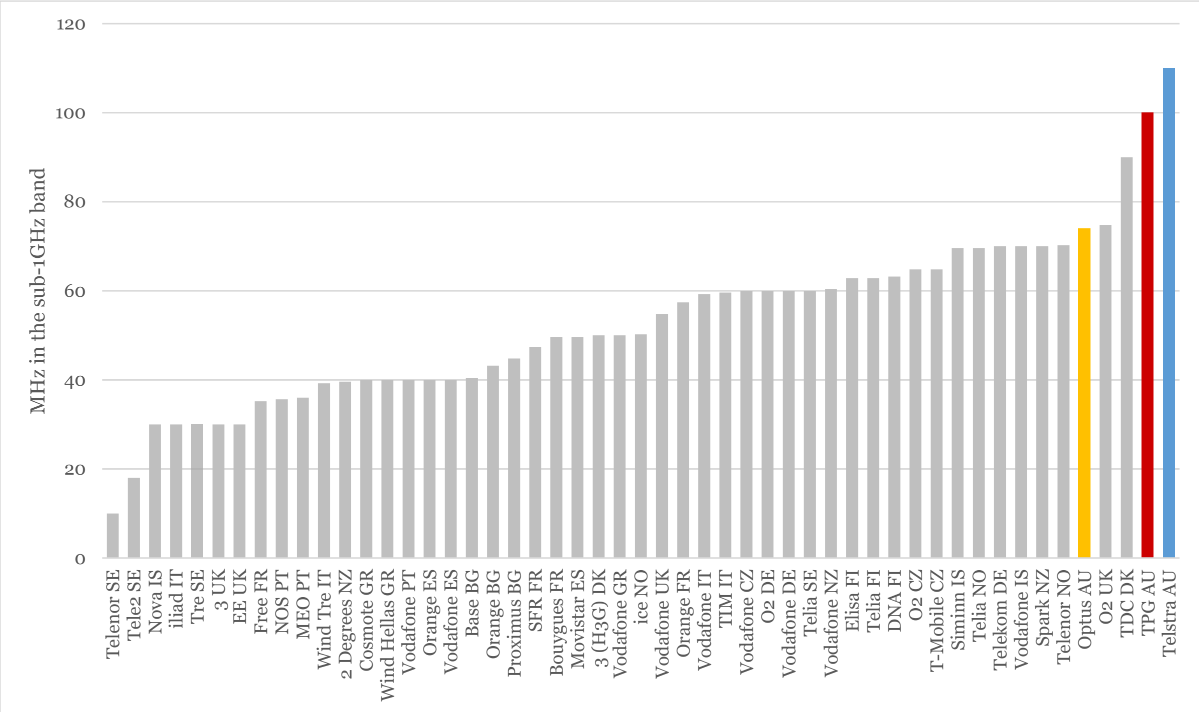
Source: Spectrum Monitoring. CEG analysis. Note: For metro area only for Australian carriers.

88. Figure 3-2 illustrates the same comparison, but includes 84 MHz spectrum in the 600 MHz band reallocated to mobile broadband. The figure shows that, on the assumptions that of the 154 MHz available in the auction, Optus wins 54 MHz while Telstra and TPG each win 50MHz of the 850/900/600 MHz bands combine (see Table 3-2), the MNOs would have a very large holdings of low frequency band spectrum relative to their international counterparts. It shows that Telstra and TPG

69 As discussed earlier in section 3.2.1 and Table 3 2, in the upcoming 850/900MHz auction in Australia, we assume that Optus wins three blocks (30 MHz), while Telstra and TPG each win two blocks (20 MHz).

would be the top two spectrum holders of all MNOs in the markets surveyed, while Optus would be above the 75th percentile among all the countries.

Figure 3-2: Spectrum holding in the sub-1GHz band by operators: with the 600 MHz reallocation



Source: Spectrum Monitoring. CEG analysis. Note: For metro area only for Australian carriers.

3.2 Demand for low frequency band spectrum for 5G services

89. In this section we consider the factors driving the demand for the 600 MHz spectrum within the time period outlined in the Green Paper. We observe reports that a relatively small block of spectrum is needed by MNOs for a 5G deployment and that this is likely to be available to MNOs without reallocating the 600 MHz spectrum band.

90. We considered whether releasing additional low frequency spectrum in the 600 MHz band would be attractive to MNOs deploying in other spectrum bands, taking into account the cost of integrating multiple low frequency spectrum bands in a 5G deployment.

3.2.1 The amount of low-frequency spectrum required for 5G services is relatively small

91. There is no definitive answer on the amount of low frequency spectrum that is required for 5G services, although Australian industry estimates that it is between 10 MHz and 20 MHz.

92. Indeed, there is some question of whether low frequency spectrum is necessary for competition between 5G rollouts. In the United Kingdom (UK), the Ofcom stated a view that low frequency spectrum was not essential for nation-wide competition between MNOs. This view was based on the following logic:[70]

- Any differences in low-frequency spectrum holdings between MNOs would create cost differences in meeting demand, but these were not large enough to lead to a "material competition concern";[71]
- The coexistence of 4G services utilising low frequency bands which, the Ofcom found, could provide similar services to 5G meant that low frequency bands were not essential to a 5G deployment.[72] The Ofcom states:[73]

  > *… it does not appear that 700 MHz spectrum will be required in order to provide 5G services. In any case, it is not clear that the ability to provide seamless 5G coverage will be a material driver of competition, as 4G technology will be able to provide a similar experience in many situations. We therefore believe that MNOs are likely to be able to compete in this area even without obtaining additional 700 MHz spectrum in the auction.*

- The only potential competition concerns related to deep indoor coverage. The Ofcom undertook modelling that showed that higher frequencies provided comparable shallow indoor coverage to low frequencies, but low frequencies had an advantage in providing higher bandwidths (10Mpbs) deep indoors. Nevertheless, the Ofcom concluded that deep coverage was not important due to:
  - Deep indoor coverage not being important to customer choice of MNO; and
  - The alternative available of using Wi-Fi for deep indoor coverage.

93. The Ofcom also modelled two alternative network configurations, one with 2 x 10 MHz at 700 MHz and the other with 2 x 5 MHz at 700 MHz.[74] This modelling shows

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70 Ofcom, Award of the 700 MHz and 3.6-3.8 GHz spectrum bands, Statement, 13 March 2020.

71 Ofcom, para 4.137.

72 Ofcom, paras 4.164-4.172.

73 Ofcom para 4.172

74 Ofcom, Award of the 700 MHz and 3.6-3.8 GHz spectrum bands, Annexes 5-18 – supporting information.

that in the case of deep indoor locations, a network based on 2 x 10 MHz of 700 MHz can outperform a network with 2 x 5 MHz of 700 MHz. A network with 2 x 5 MHz of spectrum may not have sufficient bandwidth for more data-intensive services. In the recent UK auction, each of the MNOs that licensed 700 MHz spectrum were assigned a minimum of 2x10 MHz of paired spectrum which may be indicative of the preferred block of low frequency spectrum to deploy 5G.[75]

94. In Australia, there has been no published investigation of the cost/quality trade-off for 5G deployments with differing holdings of low-frequency spectrum. The Australian MNOs hold substantially larger holdings of low frequency spectrum than their UK counterparts. Optus states that it requires a minimum of 10 MHz spectrum in the low band to fulfil the 5G services:[76]

> *Allows deployment of 10 MHz low-band channels to ensure that Australian operators can deliver 5G services meeting the specifications required by the ITU*

95. TPG Telecom in contrast states that the channel sizes for 5G start at 5 MHz and increase in the multiple of 5 MHz, hence, considers that a minimum of 10 MHz (2×5 MHz pair) is required:[77]

> *The channel sizes for 5G networks start at 5 MHz and, for sub-1 GHz, typically increase in multiples of 5 MHz thereafter. Therefore, from the perspective of setting allocation limits, the practical minimum frequency bandwidth is 2x5 MHz.*

3.2.2 MNO's spectrum plans for 5G network

96. In this section we discuss the spectrum that MNOs are likely to use as the base frequency in their respective 5G network deployments. The information currently available indicates that the MNOs will use the currently allocated low frequency spectrum, in either the 700 MHz or the reallocated 850 MHz and 900 MHz spectrum bands.

75 Ofcom, Award of 700 MHz and 3.6-3.8 GHz spectrum by auction, 05 May 2021 https://www.ofcom.org.uk/spectrum/spectrum-management/spectrum-awards/awards-in-progress/700-mhz-and-3.6-3.8-ghz-auction

76 Optus, Submission in response to ACCC Consultation Paper Allocation limits advice for 850 MHz expansion band and 900 MHz band spectrum allocation, December 2020 https://www.accc.gov.au/system/files/Optus_33.pdf

77 TPG, Submission in response to ACCC Consultation Paper Allocation limits advice for 850 MHz expansion band and 900 MHz band spectrum allocation, December 2020 https://www.accc.gov.au/system/files/TPG.pdf

3.2.2.1 Telstra is rolling out its 5G services in the 850 MHz band

97. Telstra has indicated that it will use the 700 MHz and 850 MHz bands for 5G coverage:[78]

> *We have three layers of the spectrum that we are making available to 5G. Low band; great for coverage over long distances and in building penetration from the outside.* ***We are selectively using our 850 [Mhz] spectrum, that is also used for 3G, and 700 [Mhz], that is used for 4G. [emphasis added]***

98. Recent news indicated that Telstra has completed the tests of 5G in the 850 MHz spectrum and is 'ready for commercial use'. Telstra further notes that it is testing the 700 MHz spectrum for low band 5G services as well:[79]

> *Telstra has completed tests running 5G in low-band 850MHz spectrum that it has repurposed from its 3G network, and says the capability is "now ready for commercial use".*

3.2.2.2 Optus plans to adopt 900 MHz for 5G

99. Optus indicates that it would like to use 900 MHz spectrum for 5G services if sufficient spectrum is acquired in the 850/900 MHz auction:[80]

> *Telstra currently uses its 850 MHz for 5G and has indicated it is also looking at using 700 MHz. Similarly, TPG is using its 700 MHz for 5G.* ***Optus wishes to use 900 MHz to deploy 5G service,*** *but is unable to do so due to lack of spectrum. [emphasis added]*

100. As discussed in an earlier section, the ACCC has acknowledged in its initial consultation paper that Optus does not have sufficient spectrum for 5G services while Telstra holds significantly more spectrum[81]

78 Telstra, Telstra Investor Day 2020 - Transcript, 13 November 2020 https://www.telstra.com.au/content/dam/tcom/about-us/investors/pdf%20F/2020-Investor-Day-Transcript.pdf

79 IT news, Telstra completes 5G tests using repurposed 3G spectrum, 10 March 2021, https://www.itnews.com.au/news/telstra-completes-5g-tests-using-repurposed-3g-spectrum-561974

80 Optus, Submission in response to ACCC Consultation Paper Allocation limits advice for 850 MHz expansion band and 900 MHz band spectrum allocation, December 2020 https://www.accc.gov.au/system/files/Optus_33.pdf

81 ACCC, Allocation limits advice for 850 MHz expansion band and 900 MHz band spectrum allocation, Consultation paper, November 2020.

there is significant asymmetry of holdings in the sub-1 GHz bands. Telstra has the highest amount of low-band spectrum, holding 46 per cent of all available spectrum in metropolitan areas and 54 per cent in regional areas. TPG also holds a substantial amount of low-band spectrum. By contrast, ***Optus holds significantly less lowband spectrum (only 15 per cent of total low-band spectrum available) than Telstra and TPG****. Optus only holds 700 MHz band spectrum and no 850 MHz band spectrum. [emphasis added]*

101. The ACCC has subsequently advocated for an allocation limit of 80MHz across sub 1 GHz spectrum for any MNO, which provides Optus an opportunity to acquire sufficient spectrum to compete in the market: [82]

The ACCC considers that the recommended limit will provide a reasonable opportunity for Optus to acquire the spectrum it needs to compete effectively in the mobile services market in the medium to long term, but does not prevent Telstra and TPG from participating in a potential price-based allocation.

102. In line with the advice from the ACCC, Minister has published the Exposure Draft instrument proposing a competition limit of 82 MHz in response to the recommendation from the ACCC.[83] This competition limit would be applied to both metropolitan and regional areas.

Table 3-4: Spectrum allocation assuming Telstra and TPG acquire the maximum amount of spectrum allowed in the 850/900MHz auction

	Spectrum before auction	Spectrum after 850/900 MHz auction
Telstra	60 (70 for regional)	80
Optus	**20**	**40**
Vodafone/TPG	50 (40 for regional)	80
Total	**130**	**200**

Source: ACCC, ACMA. Note: The spectrum before auction column has excluded the 900MHz spectrum bands that the MNOs currently holds but due for reallocation.

[82] ACCC, Allocation limits advice for the 850/900 MHz spectrum allocation Public version March 2021, https://www.accc.gov.au/system/files/ACCC%20advice%20to%20the%20Minister%20on%20allocation%20limits%20for%20the%20850_900%20MHz%20allocation%20March%202021.pdf

[83] The additional 2 MHz will be used as a guard band between the 824–825 MHz and 869–870 MHz. The primary purpose is to facilitate agreement between the licensees of the lower 900 MHz lot and adjacent 850 MHz band spectrum. Radiocommunications (Spectrum Licence Limits—850/900 MHz Band) Direction 2021, 27 April 2021, https://www.communications.gov.au/have-your-say/850900-mhz-auction-allocation-limits-exposure-draft

103. Since Telstra already has 60 MHz of sub-1 GHz spectrum in metro areas and 70 MHz in regional areas, the maximum amount that Telstra could bid for under these proposed limits in the 850/900 MHz auction would be 20 MHz and 10 MHz, respectively. Since TPG holds 50 MHz of sub-1GHz spectrum in the metro areas and 40 MHz in regional areas, the maximum amount TPG can bid for are 30 MHz and 40 MHz respectively.

104. Therefore, even if we assume that Telstra and TPG bid for the maximum amount of spectrum in the 850/900 MHz auction, Optus would still have the ability to acquire at least 20 MHz from the auction under the proposed competition limits.

3.2.2.3 TPG Telecom also has sufficient spectrum for 5G in the 700MHz band

105. Following the merger between Vodafone and TPG, the amount of spectrum available to the merged party (TPG) has increased significantly.

106. The ACCC has acknowledged that TPG Telecom has sufficient spectrum for the 5G services. TPG Telecom could use its 700MHz spectrum to deploy 5G services:[84]

> *TPG has been using the 850 MHz for 4G services. Following the merger, TPG is now able to use its 700 MHz holdings for either 4G or 5G services.*

3.2.3 There will be higher costs with a dual low frequency deployment

107. If MNOs commit to the existing sub-1 GHz spectrum bands to roll out their 5G services, there will be additional costs of using 600 MHz to add capacity to those networks. As noted in Ofcom commissioned research, spectrum aggregation will incur additional costs and complexity to the MNOs, especially aggregating spectrum across bands (inter-band, non-contiguous).:[85]

> *Inter-band carrier aggregation undoubtedly incurs additional cost, complexity and some loss of performance relative to intra-band aggregation or deployment of wider carriers [emphasis added], though these are difficult to quantify at this stage.* ***It is generally preferable for an operator to have sufficient spectrum available in a single band to meet the required data throughput rather than having to do this by combining carriers in different frequency bands****, but*

84 ACCC, Allocation limits advice for 850 MHz expansion band and 900 MHz band spectrum allocation Consultation paper, November 2020, https://www.accc.gov.au/system/files/MACE%20-%20850_900%20-%20Allocation%20limits%20advice%20consultation%20paper%20-%2023%20October%202020%20%289%29.pdf

85 Ofcom, Frequency Band Support for Future Mobile Handsets, January 2014, https://www.ofcom.org.uk/__data/assets/pdf_file/0035/69785/future_mobile_handset.pdf

the need to continue supporting legacy services in some bands and limited available bandwidth in others makes this impractical in many cases.

108. The ACMA has observed that larger contiguous blocks are public welfare enhancing due to scale efficiencies:[86]

Combined allocation of the 900 MHz and 850 MHz under this option offers appropriate incentives for an incumbent licensee to potentially exit the 900 MHz band in favour of the 850 MHz band, resulting in holdings of larger contiguous blocks. Mobile network operators have increasing returns to scale between 5 MHz and 10 MHz holdings, and therefore larger contiguous blocks are public welfare-enhancing.

109. Additional cost would also be incurred due to the costs of sourcing antennae capable of utilising both 600 MHz and 900 MHz bands (or deploying multiple low frequency antennae). We understand that this configuration is not currently supported by suppliers.[87] Global demand for such a configuration may be limited given the small number of jurisdictions that have allocated both the 600 MHz and 900 MHz bands to mobile services.

86 ACMA, Reconfiguring the 900 MHz band Options paper, April 2019 https://www.acma.gov.au/consultations/2019-08/reconfiguring-900-mhz-band-consultation-112019

87 For example, the RFS World Antenna supports 617-894MHz in the sub-1GHz bands, https://www.rfsworld.com/pim/product/pdf/APXVAALL18_43-U-NA20

4 Value lost in reallocation of 600 MHz spectrum

110. In this section we provide our analysis of the likely discount, or loss in value, that will result from an allocation of the 600 MHz spectrum post-2026 (the timing proposed in the Green Paper). Our analysis includes:

a. A model of the impact on the value of spectrum from a release of additional 600 MHz spectrum for 5G deployment. We model the value impact on both the 850/900 MHz spectrum auction which will be assigned in 2022 and on the proposed subsequent 600 MHz auction;

b. A case study comparing auction results in Germany and France, demonstrating the discount incurred in Germany as a result of the regulator supplying additional low frequency spectrum beyond what was required by MNOs for coverage; and

c. An analysis of the discounted to prices paid in spectrum allocations that are out-of-sync with mobile technology deployment.

4.1 Model of value loss from additional spectrum supply

111. In this section we use regression analysis to test whether the prices paid in spectrum auctions for sub-1GHz bands are affected by the quantity of spectrum offered in each auction. The analysis finds that increased supply of spectrum band drives down the unit spectrum prices paid in an auction. We also find that a supply and demand imbalance, where there exists an excess supply, will lead to lower unit prices for spectrum.

112. We model the impact on the price paid for low frequency spectrum of the reallocation of the 600 MHz spectrum. We estimate that the release of 84 MHz in the 600 MHz band will result in an estimated unit price to $0.55/MHz/POP, with a total value for the 600MHz band estimated to be $1.16 billion.

113. The regression analysis predicts that the reallocation of the 600MHz band following the planned reallocation of the 850/900 MHz will result in a discount of 52% in the price paid in both auctions. For the 600 MHz spectrum this represents around a $1.3 billion loss in value compared with reallocating the 600MHz spectrum on a standalone basis. This result is consistent with standard economic theory that the amount of spectrum supplied into the market matters to the value of the spectrum realised such that an increase in supply is likely to lead to lower prices paid, other things equal.

4.1.1 The relationship between the price paid for spectrum and the quantity of spectrum auctioned

114. In this section we set out the regression model which we use to estimate the relationship between the price paid for spectrum and the quantity of spectrum auctioned. We discuss the specification of the model and the variables included in the model.

115. Regression analysis is a common analytic tool used to estimate the relationship between price and the supply and demand of goods in a range of markets. The technique can assist in answering the primary question of interest in our analysis: Will a change in supply and demand conditions lead to a change in prices in the spectrum auction market? More specifically, what would be the expected price that could be realised for the 600 MHz spectrum and how much will the price be impacted given the timing of the reallocation following the assignment of the 850/900 MHz band?

116. We estimate our regression model based on data from 28 auctions of sub-1 GHz across a number of OECD countries.[88] The dataset covers auctions that occurred between 2010 and 2020. We treat each auction as a single data point regardless of the year in which the auction occurs, meaning our analysis takes the form of a pooled regression. We adopt a regression model of the general form:

Spectrum Price/MHz/Pop = function (winner/bidder ratio, spectrum sold, GDP per capita, land area)

117. In the model *price* is the price of the spectrum for each auction included in the survey. We have collected and calculate the price of spectrum in each of the auctions. These prices are then converted to a per MHz per population term, adjusted for licence duration, price level of the country (Purchasing Power Parity) and inflation.[89]

118. We have included two explanatory variables that measure the relative competitiveness of the auction and the supply of spectrum:

- the winner/bidder ratio; and
- the volume of spectrum sold in each auction.

119. The winner/bidder ratio is defined as the number of winners as a percentage of total number of bidders participating in the auction. The winner/bidder ratio reflects the supply and demand balance within the auction. We expect that winner/bidder ratio

88 These include Australia, Belgium, Canada, Czech Republic, Denmark, Finland, France, Germany, Greece, Italy, New Zealand, Portugal, Spain, Sweden, the United Kingdom, the United States.

89 The price has been adjusted to 2018 level. The estimated spectrum price will be converted to 2021 level assuming an inflation rate of 1.8%. A more detailed discussion on the conversion is in Appendix D.

will be negatively correlated with the spectrum price - the spectrum price will be higher if there are more parties seeking to acquire the spectrum.

120. The volume of spectrum variable is the volume of spectrum successfully sold in the auction (in MHz). Other things equal, we expect that the spectrum sold is negatively correlated with the price, which means that more spectrum supplied in the auction of the sub-1GHz spectrum will lower the spectrum price. This is our primary variable of interest as it will allow us to estimate the effect on price of the additional 600 MHz spectrum being offered to mobile operators.

121. To further explain country specific characteristics, we have collected two explanatory variables to be used in the regression: GDP per capita and land area. GDP per capita is sourced from the World Bank.[90] It is a proxy for the demand in the mobile telecommunication sector. We expect that demand for mobile service will be higher for countries with a higher GDP per capita level, which translates to higher bidding for spectrum prices.

122. The land area is sourced from the World Bank.[91] It is a demand proxy, which is expected to be positively correlated with the spectrum price. We expect that land area would be a proxy for demand for sub-1GHz spectrum more so than demand for mid and high frequency spectrum. An increase in land area means a greater need for spectrum capable of achieving coverage at lower costs. Hence, we expect the coefficient on this variable to be positive, i.e., increased in land area implies higher demand for sub-1 GHz spectrum, which translates to higher bidding prices.

4.1.2 Prices paid are negatively correlated with the volume of spectrum auctioned

123. The table below shows the regression results. The coefficients on both competition measures are negative as expected.[92] The regression result shows that coefficient on quantity of spectrum sold is -0.01. This implies that when the amount of spectrum available on auction increases from, say, from 60 MHz to 70 MHz, we observe the price of spectrum decreases by $0.10/MHz/Pop (-0.01*10).[93]

90 OECD, GDP per capita (current US$), https://data.worldbank.org/indicator/NY.GDP.PCAP.CD

91 World Bank, Land area (sq. km), https://data.worldbank.org/indicator/AG.LND.TOTL.K2

92 Both are also statistically significant at the conventional 5% level.

93 The coefficient on land area is positive as expected. This implies larger land area is associated with higher demand for low-band spectrum to achieve coverage of population. The coefficient on GDP per capita is negative which does not conform to prior expectations. There is evidence that suggests in countries in lower income countries, governments are forgoing a more efficient allocation or higher welfare in favour of extracting higher revenue from auctions. See GSMA, Spectrum pricing in developing countries Evidence to support better and more affordable mobile services July 2018, https://www.gsma.com/spectrum/wp-content/uploads/2018/12/2018-07-17-5a8f746015d3c1f72e5c8257e4a9829a.pdf

Table 4-1: Regression with auction market variables, land area and GDP per capita

	Winner-Bidder ratio only	Size of spectrum sold only	Both competition variables
Constant	2.76***	2.28***	3.13***
	(0.50)	(0.37)	(0.50)
Winner - Bidder Ratio	-1.30**		-1.06**
	(0.48)		(0.46)
Spectrum sold (MHz)		-0.01**	-0.01**
		(0.00)	(0.00)
Land Area (million sq km)	0.10***	0.13***	0.11***
	(0.02)	(0.02)	(0.02)
GDP (thousands) Per Capita	-0.02***	-0.02***	-0.02***
	(0.00)	(0.00)	(0.00)

*Source: CEG analysis. Standard errors are shown in brackets. *, ** and *** implies the coefficients are significant at 10%, 5% and 1% p-value respectively.*

124. The regression result shows that the coefficient on winner-bidder ratio is -1.06. This implies that if the winner-bidder ratio increases from 0.5 (2 bidders competing for 1 license) to 1 (2 bidders competing for 2 licenses), we would expect the price of spectrum to decrease by half or by 53 cents per MHz per pop (-1.06*0.5).

125. A higher winner-bidder ratio implies that the supply of spectrum is large compared to the number of bidders. A larger supply of spectrum indicates a potentially less competitive auction, other things equal.

4.1.3 The predicted value impact of the 600 MHz allocation on both the 850/900 MHz auction and the 600 MHz auction

126. In this section we describe the predicted value impact of reallocating the 600 MHz spectrum on the expected prices paid in both the 850/900 MHz and the 600 MHz auctions.

127. The table below shows the predicted spectrum pries from the regression model.[94] The prediction is that in a standalone auction of the 600 MHz spectrum (84MHz), the predicted spectrum price would be $1.15/MHz/POP. However, if both the 600MHz and 850/900MHz are assigned, the volume of spectrum will increase from 84MHz to 154MHz, leading to a decrease in the expected price paid from $1.15/MHz/POP to $0.55/MHz/POP. This implies the total amount paid for the 84MHz of 600MHz spectrum would be expected to be reduced from $2.42 billion to $1.16 billion.

94 We assume that all three Australian MNOs will bid and will be able to win some spectrum in the auction. That is, we assume a winner-bidder ratio of 1.

Table 4-2: Summary of price difference estimated from the regression

	Predicted spectrum price (AU$/MHz/pop)	Total spectrum value for 600MHz spectrum (AU$ billion)
Only 600MHz spectrum are available	1.15	2.42
Both 600MHz and 850/900MHz are available	0.55	1.16
Difference (52% discount)	**0.60**	**1.26**

Source: CEG analysis. Assuming there are 3 bidders and all three bidders win spectrums rights in the auction. Assuming no change in Australia GDP per capita from 2019 and land area remains unchanged. We use a 1.8% inflation rate per year to convert the 2018 price to 2021 price.

128. We note our regression model and prediction are consistent with similar models in the economic literature. For example, Madden and Suenaga (2015) also examine the factors that influence spectrum prices in 27 auctions spanning from 2000 to 2011.[95] They conclude that:

> *… auction theory conjecture that more intense competition among bidders places upward pressure on prices is supported*

129. Their results show that an increase in the number of bidders relative to the number of licences available in an auction is associated with an increase in spectrum prices (price/MHz/Pop). When the increase in the number of bidders equals the number of licences on offer (e.g., an increase of 10 bidders, from 5 to 15, when there are 10 licences being auctioned), the spectrum price would increase by US$1.33 /MHz/POP.

4.2 France and Germany, a comparison of spectrum auction results

130. A case study comparing the results of low frequency spectrum auctions in Europe provides additional insights into the likely effects of the reallocation of the 600 MHz spectrum band in Australia.

131. The following case study compares the outcomes of spectrum auctions in France and Germany between the early- and mid-2010s. Both France and Germany auctioned 60 MHz of spectrum in the 800 MHz band in the early-2010s. In the mid-2010s, both France and Germany auctioned additional sub-1 GHz spectrum. In France, the 2015 auction offered 60 MHz of spectrum to the market. In contrast, in 2015 Germany auctioned an additional 130 MHz of spectrum in the 700 MHz and 900 MHz spectrum bands. This is comparable to the circumstance in Australia, where there is a process in train to auction 84 MHz of sub-1 GHz spectrum in the

95 Gary Madden & Hiroaki Suenaga (2016): The determinants of price in 3G spectrum auctions, Applied Economics, DOI: 10.1080/00036846.2016.1254342

850/900 MHz bands and the Government is considering allocating the 600 MHz spectrum to mobile broadband which will increase the total spectrum to 154 MHz.

132. The table below compares the auction results for sub-1 GHz spectrum sold in the France and Germany, since 2010. Both countries held two auctions between 2010 to 2015 for the development and expansion of 4G network. In the French case, the auction of the 700 MHz band in 2015 yielded a similar unit value to the 800 MHz auction in 2011.[96, 97] That is, both auctions yielded a unit price of around $1.1/MHz/Pop.

133. In contrast in the German case, while the 800 MHz band auction in 2010 offered 60 MHz to the MNOs, the 700/900 MHz band auction in 2015 offered as much as 130 MHz. We observed that the unit price paid for the 130 MHz of spectrum in the 700/900MHz band in 2015 was at a **74% discount** from the 800MHz auction in 2010.[98, 99] The lower price paid was attributed to the lower coverage value that additional spectrum would supply:[100]

> *The deployment of LTE in the 800MHz band already provides LTE coverage and better in-building penetration. Hence additional 700MHz spectrum has a lower "coverage value" compared previously acquired 800MHz spectrum.*

96 ARCEP, ARCEP publishes the results of the allocation procedure for 4G mobile licences in the 800 MHz band (the digital dividend) December 23, 2011, https://en.arcep.fr/news/press-releases/view/n/arcep-publishes-the-results-of-the-allocation-procedure-for-4g-mobile-licences-in-the-800-mhz-band-the-digital-dividend.html

97 ARCEP, Final results of the allocation procedure, November 24, 2015https://en.arcep.fr/news/press-releases/view/n/final-results-of-the-allocation-procedure.html

98 Bundesnetzagentur, Frequency Award 2010, https://www.bundesnetzagentur.de/EN/Areas/Telecommunications/Companies/FrequencyManagement/ElectronicCommunicationsServices/FrequencyAward2010_Basepage.html?nn=324045

99 Bundesnetzagentur, Mobile Broadband - Project 2016, https://www.bundesnetzagentur.de/EN/Areas/Telecommunications/Companies/FrequencyManagement/ElectronicCommunicationsServices/MobileBroadbandProject2016/project2016_node.html

100 Telecoms, The German spectrum auction: Failure to negotiate? June 2015, https://telecoms.com/opinion/the-german-spectrum-auction-failure-to-negotiate/

Table 4-3: Spectrum auction in France and Germany

Country	Auction	Frequency (MHz)	Volume (MHz)	AUD/MHz/Pop	Discount rate
France	2011 Auction	800	**60**	**1.11**	
France	2015 Auction	700	**60**	**1.14**	**-3%**
Germany	2010 Auction	800	**60**	**1.57**	
Germany	2015 Auction	700 and 900	**130**	**0.41**	**74%**

Source: Arcep and Bundesnetzagentur. Note: The prices are adjusted by PPP and inflation. Prices are also adjusted for licence duration, based on a standard 15 years. The final result of the auction could be affected by a number of factors, including the number of competing operators, the reserve price, the design of the auction, the coverage obligation, the capacity of incumbent MNOs.

134. This case study is consistent with the results of our regression analysis. It shows that, particularly for low frequency spectrum, additional spectrum may lower the unit price paid in auctions. The implication for the timing in the Green Paper is that a reassignment of the 600 MHz spectrum for 5G deployment is likely to substantially influence the price paid for the 850/900 MHz spectrum which is candidate base frequency for 5G deployment (in addition to the direct effects on the 600 MHz spectrum reallocation).

4.3 U-shaped prices from spectrum auctions

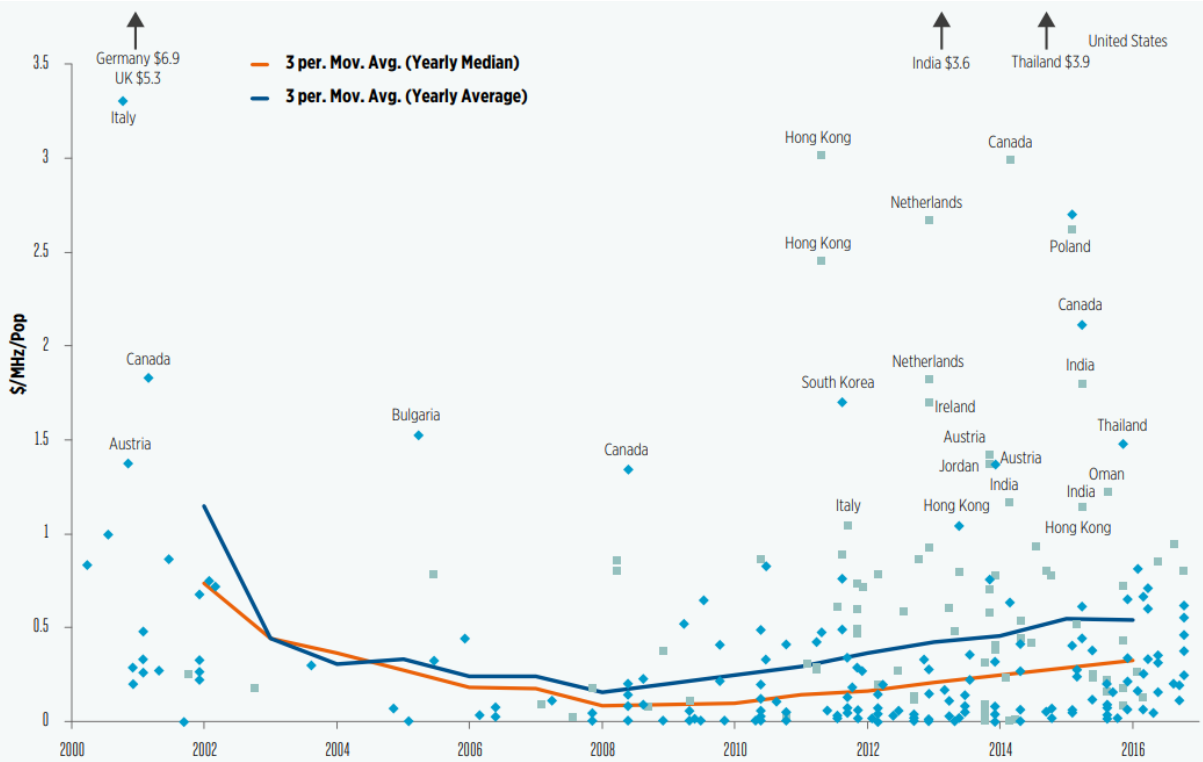
135. In this section we examine the pattern of prices from spectrum auctions over time. We find that prices have followed a distinct U-shape, with prices peaking around the times of the deployment of each generation of mobile network technology deployment (i.e., for 3G and then for 4G), while a "dip" in prices occurs between the release of two mobile technologies.

136. The figure below sets out the historical price trends for sub-1 GHz bands (green dots) and over-1 GHz bands (blue dots). The average price follows a U-shaped pattern. The expansion of 3G and 4G is reflected in the high prices achieved in the early awards.[101] The timing of network deployment is likely to be a combination of perceived demand for services in each jurisdiction as well as the cost of deployment. The cost of deployment is heavily influenced by economies of scale in network infrastructure. This means that as more and more countries order and deploy equipment the cost of manufacturing the equipment, and hence the price, declines. This leads to a relatively

[101] GSMA, Effective Spectrum Pricing: Supporting better quality and more affordable mobile services, February 2017, https://www.gsma.com/spectrum/wp-content/uploads/2017/02/Effective-Spectrum-Pricing-Full-Web.pdf

coincident deployment of each generation of mobile technology in major economies around the world.

Figure 4-1: U-shaped path of spectrum prices



Source: GSMA. Note: Green = Prices for coverage bands below 1 GHz; Blue = Prices for capacity bands above 1 GHz. Prices per MHz pop are adjusted for inflation and were converted to USD purchasing power parity (PPP) rates. Prices are also adjusted for licence duration, based on a standard 15 years.

137. The 3G auctions began in around 2000, while the 4G standards were completed in around 2008 with technological deployment of 4G beginning from around 2010 worldwide.[102]

138. The number of spectrum auctions and the price paid in those auctions closely follows the development of 3G and 4G deployment:[103]

> *From 2000-01, there was a large number of awards of spectrum suitable for 3G (2100 MHz and PCS). This was followed by a quiet period of five*

102 GSMA, Brief History of GSM & the GSMA https://www.gsma.com/aboutus/history

103 GSMA, Effective Spectrum Pricing: Supporting better quality and more affordable mobile services, February 2017, https://www.gsma.com/spectrum/wp-content/uploads/2017/02/Effective-Spectrum-Pricing-Full-Web.pdf

years, with relatively few spectrum awards, which coincided with the slow launch of 3G services.

Since late 2007 (when Norway awarded the 2600 MHz band), there has been a significant increase in the number of awards each year, driven by the need to find new bands and repurpose old ones for 4G mobile broadband.

139. Based on this trend we would expect to see peaks coincident with the deployment of new technologies. On the basis of a technology evolution every 8 to 10 years, we may not expect to see another peak until late into the current decade.

140. The observed price trend is U-shaped, meaning that the price of spectrum is at its peak price level at the beginning of the new expansion of technology: [104]

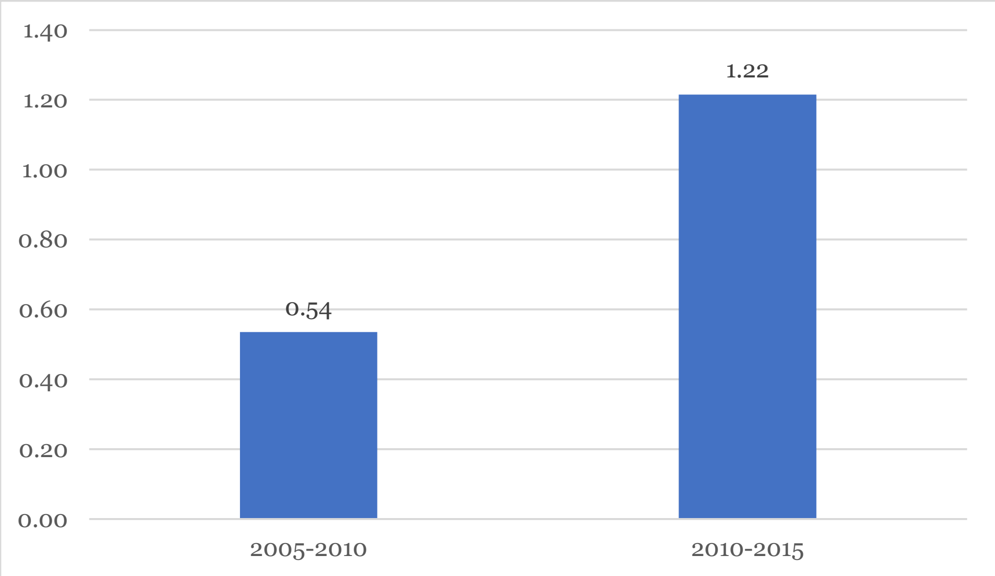
This follows a U-shaped path. The beginning of the 3G era coincided with the so-called "tech bubble", which generated huge enthusiasm regarding the potential of 3G data services. This was ***reflected in the very high prices achieved in some early awards****, most notably the UK and German 3G auctions in 2000, which raised an exceptional $5.30 and $6.90 per MHz/pop respectively. Subsequently, there was a sharp drop in prices for 3G spectrum, and most awards for the remainder of the 2000s generated modest prices. Since 2008, however,* ***there has been an upward trend in prices, coinciding with the take-off of 4G services [emphasis added]****.*

141. The "dip" in prices paid for spectrum between the release of mobile technologies can be quantified as follows.

142. The bar chart below shows the average price /MHz/Pop in the sub-1 GHz band using data from GSMA as reported in the table above in green dots. It compares the observed average price from the time of 4G deployment (five years from 2010) with the average price in the period prior. It shows that the average price of sub-1 GHz spectrum in this period was around $1.22/MHz/Pop, whereas, the price paid in the period before (2005-2010) was $0.54/MHz/Pop. This is a **discount of approximately 56%**.

104 GSMA, Effective Spectrum Pricing: Supporting better quality and more affordable mobile services, February 2017, https://www.gsma.com/spectrum/wp-content/uploads/2017/02/Effective-Spectrum-Pricing-Full-Web.pdf

Figure 4-2: Average sub-1GHz spectrum prices from 2005 to 2015 (AUD/MHz/Pop)



Source: GSMA, CEG analysis. Note: The results are PPP adjusted. It includes only sub-1GHz spectrum auctions from the scatter plot.

5 International benchmarks

143. In this section we provide the results of a survey of prices paid in low frequency spectrum auctions in OECD countries (and elsewhere).

5.1 Market mechanisms to value spectrum

144. One of the primary goals of spectrum management is to ensure that spectrum is allocated to the use which values the spectrum the most. This is consistent with the goal of economic efficiency as it maximises welfare from use of the spectrum. Additional goals include ensuring that public and community services have access to adequate spectrum.[105] In practice, there is some difficulty identifying the highest value use of spectrum a priori. Spectrum allocation and assignment would therefore ideally be carried out through market mechanisms such as auctions. Auctions are preferred when they can reveal the value users place on the spectrum and allocated it to the user with the highest value.

145. Auctions have been embraced by governments and regulators around the world as the primary means of assigning spectrum. Auctions have a range of benefits beyond their primary objective of achieving spectrum assignment is efficient (i.e., ensuring spectrum is allocated to uses where it is most productive). These include reducing rent seeking by parties who want to be protected from market forces. Hazlett et al (2012) observe:[106]

> *Assigning wireless licenses to high bidders places assets with the most productive firms, reduces rent-seeking costs incurred by comparative hearings or lotteries, and captures license rents for the public treasury. This last benefit potentially increases efficiency, in that funds generated without the use of taxes do not cause tax-distorting social losses. Each tax dollar raised, for instance, is expected to cost society about $0.33 in deadweight loss. Auction dollars, as pure transfers, cost less.*

146. As noted by Hazlett et al (2012), the lump sums that are achieved in auctions can be an efficient way of raising Government revenue if they do not directly distort consumption decisions (i.e., due to prices being raised further above cost). This is in contrast to levies that are based on the sales of a licensee; these levies would represent a unit cost and will likely flow through to higher price, reducing consumption of services.

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105 Radiocommunications Act 1992.

106 Hazlett, T., Munoz, R., and Avanzini, D., (2012) "What Really Matters in Spectrum Allocation Design", *Journal of Technology and Intellectual Property*, Volume 10, Issue 3, Article 2.

147. The lump sums paid in auctions could have an indirect effect on pricing outcomes through affecting the number of firms that enter the market. In standard oligopolist market models, the markup above costs that firms apply when setting prices is a function of the number of firms, with the markup decreasing the more firms in the market.[107]

5.2 Benchmark on low frequency band spectrum auction

148. The auctions of sub-1 GHz spectrum provide a meaningful indication of the valuation of the 600 MHz spectrum for mobile services. We consider the prices paid for spectrum in bands below the sub-1 GHz spectrum which have been allocated to mobile broadbands services. This includes the 600 MHz, 700 MHz, 850 MHz and 900 MHz spectrum bands. These low frequency bands have similar properties for propagating mobile broadband services,[108] such that they would be considered economic substitutes. In economics, goods and services that are substitutes tend to converge in price.[109] The results of the auctions surveyed therefore provide an indication of the potential revenue realised from reallocating this spectrum.

149. We have surveyed 28 major auctions of sub-1 GHz spectrum in the period between 2010 to 2021 which we consider are comparable. These are the OECD countries with similar economic conditions to Australia in terms of GDP per capita.[110]

150. We note that although some countries do have a similar level of economic development as Australia, the spectrum auctions could have a different format (e.g., the type of auction used). This may influence the price realised in auctions, though the developments in auction design mean that there is lower probability of this influencing outcomes today than historically. In addition, we note that some auctions

107 The Cournot equilibrium with multiple firms having symmetric costs results in a price markup with the following formula:

$$p^* - c = \frac{a - c}{n + 1} > 0$$

where the industry demand function is linear, such that $P = a - bQ$, c is the marginal cost of each firm i such that the cost function for each firm is $TC = cq_i$, and n is the number of firms in the industry. The formula shows that the price markup declines as the number of firms increases. Jehle and Reny, *Advanced Microeconomic Theory*, Third Edition, Pearson Education Limited, Essex, 2011, pp. 174-175

108 Kerans, A., Vo, D., Conder, P. and Krusevac, S., (2011), May. Pricing of spectrum based on physical criteria. In 2011 IEEE International Symposium on Dynamic Spectrum Access Networks (DySPAN) pp. 223-230

109 Goods that are substitutes tend to converge in price because price differential drive consumers to switch to the cheaper alternative. When goods are perfectly substitutable, they will have the same price (this is known as the law of one price).

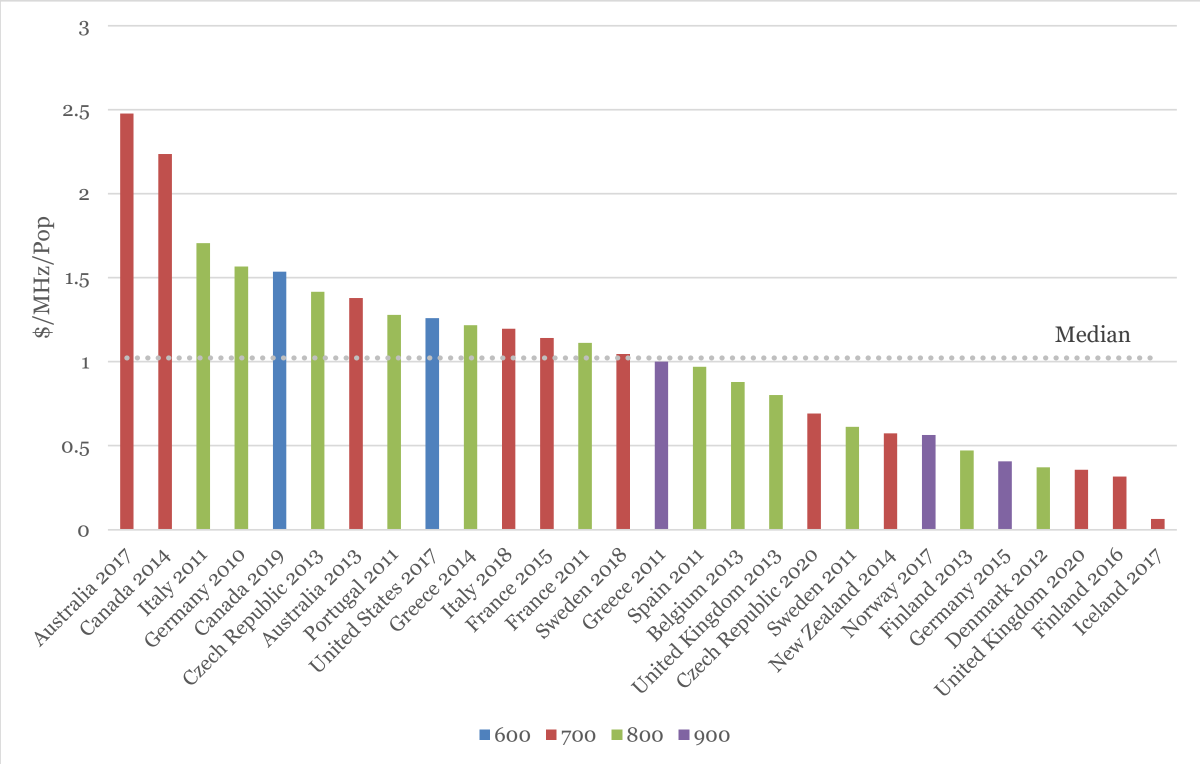
110 These include Australia, Belgium, Canada, Czech Republic, Denmark, Finland, France, Germany, Greece, Italy, New Zealand, Portugal, Spain, Sweden, the United Kingdom, the United States.

bundle the spectrum in sub-1 GHz together with bands over 1 GHz. Without information to separately estimate the unit price for the sub-1 GHz band these auctions are not included in our analysis.[111]

151. We calculate the price/MHz/Pop per year adjusted for licence duration and the difference in purchasing power across each country. We present the price in each jurisdiction in dollars as at 2018 (i.e., adjusted for inflation).[112]

152. The following figure and table illustrate the auction results. The median spectrum price/MHz/Pop is $1.08, with the 25th percentile being $0.60 and 75th percentile being $1.43. The average (or mean) price is $1.08/MHz/Pop, which is approximate to the median.

Figure 5-1: Spectrum auction and prices (AU$/MHz/Pop)



Source: Telecommunication regulators and media, CEG analysis. Note that the Spain and Portugal auction in 2011 includes both 800 MHz and 900MHz bands, the Germany auction in 2015 includes both 700MHz and 900MHz bands, the Iceland auction in 2017 includes both 700Mhz and 800MHz bands. We have categorised these three into the majority band they auctioned in. The numbers are in 2018 terms.

111 The countries that have not been included are Austria, Ireland, Switzerland, Netherlands, Norway.

112 The adjustments are explained in detail in Appendix C.

Table 5-1: International benchmarking of spectrum auctions for sub-1GHz band

Country	Band (MHz)	Year	Spectrum sold (MHz)	Licence duration (years)	Population (million)	PPP (AUD, 2018)	Amount raised (million AUD, PPP adjusted)	AUD/MHz/Pop (2021)
Australia	700	2013	60	15	25.0	1.00	1,887	**1.38**
Australia	700	2017	30	12	25.0	1.00	1,821	**2.48**
Belgium	800	2013	60	20	11.4	0.53	562	**0.88**
Canada	700	2014	68	20	37.1	0.83	5,287	**2.24**
Canada	600	2019	60	20	37.1	0.83	3,481	**1.54**
Czech Republic	800	2013	60	15	10.6	8.55	852	**1.42**
Czech Republic	700	2020	60	15	10.6	8.55	467	**0.69**
Denmark	800	2012	60	22	5.8	4.67	124	**0.37**
Finland	800	2013	60	20	5.5	0.59	151	**0.47**
Finland	700	2016	60	17	5.5	0.59	103	**0.32**
France	800	2011	60	20	67.0	0.52	4,194	**1.11**
France	700	2015	60	20	67.0	0.52	4,448	**1.14**
Germany	800	2010	60	15	82.9	0.51	7,004	**1.57**
Germany	900	2015	130	17	82.9	0.51	4,222	**0.41**
Greece	900	2011	70	15	10.7	0.39	763	**1.00**
Greece	800	2014	60	15	10.7	0.39	791	**1.22**
Iceland	700	2017	50	15	0.4	94.33	1	**0.06**
Italy	800	2011	60	17	60.4	0.47	5,779	**1.71**
Italy	700	2018	60	15	60.4	0.47	4,335	**1.20**
New Zealand	700	2014	90	18	4.8	1.00	239	**0.57**
Norway	900	2017	40	15	5.3	6.77	117	**0.56**
Portugal	800	2011	70	15	10.3	0.40	865	**1.28**

Spain	800	2011	60	19	46.8	0.44	2,552	**0.97**
Sweden	800	2011	60	14	10.2	6.09	354	**0.61**
Sweden	700	2018	40	20	10.2	6.09	425	**1.05**
United Kingdom	800	2013	60	20	66.5	0.47	2,961	**0.80**
United Kingdom	700	2020	60	20	66.5	0.47	1,470	**0.36**
United States	600	2017	84	12	326.7	0.69	33,756	**1.26**
Median								**1.08**

Source: ACMA, Ofcom, Industry Canada, Radio Spectrum Mgmt NZ, bundesnetzagentur, EETT, Anacom, PTS, FCC, Arcep and other regulators, GSMA, Analysys Mason and other media and industry bodies, World Bank, CEG analysis. Note: There are a number of other auctions we have surveyed but not included in this analysis. Those auctions bundle sub-1GHz and above-1GHz spectrums and did not disclose pricing information separately for 1GHz spectrum bands. The prices for each country are presented in 2018 term because of data availability. The final median number have been adjusted to 2021 term using an annual inflation rate of 1.8%.

5.2.1 Regression of value of low frequency band spectrum

153. In section 4.1, we describe a regression analysis that we use to estimate the impact of additional sub-1 GHz spectrum being allocated to mobile services as per the proposal in the Green Paper.

154. This same analysis of the factors that might explain the variation in prices across these comparable markets is relevant to comparing the absolute value of the spectrum observed in other countries to Australia. The regression analyses whether the variation in prices is explained by a number of factors including the GDP per capita in 2018 Australian dollars, land area (in million square kilometres), the auction winner-bidder ratio[113] and the spectrum sold.[114] We use this regression to predict a value of the 600 MHz in Australia.

155. We find based on this regression that the estimated value of the 600 MHz on a standalone basis would be $1.15/MHz/POP in 2021 dollars and a total revenue of $2.42 billion from 84 MHz of spectrum.

156. For the reasons discussed in the previous section we consider this would be an overestimate of the price that would be realised given the timing of the auction and reassignment proposed in the Green Paper.

5.3 Alternative approaches to estimating value

157. We considered, but do not use alternative approaches to determining spectrum value, including engineering values from cost models and values reported in secondary trading markets. For example, it is common to value spectrum based on engineering values. These values are calculated based on models that cost the provision of services with and without an increment of spectrum. These models produce an estimate of the value of the addition spectrum to the intended use, which is typically an estimate of the costs saving in providing services from additional spectrum. For example, in the case of mobile networks, additional spectrum can mean cost savings from needing to deploy fewer sites providing services. These savings represent the value of the spectrum in its proposed use. These engineering estimates of value are highly sensitive to the assumptions made by the cost modeller. These include assumptions regarding the size and scale of the operator providing services. As such, there tends to be wide range of estimates.

158. In some markets, spectrum can, and is, traded in secondary markets. The price paid in secondary markets is likely to overestimate the opportunity cost of spectrum. This

[113] Winner-bidder ratio is the ratio of the number of winners versus the number of bidders. For example, if the results of an auction assigned spectrum to two of three bidders in the auction, the winner-bidder ratio was 2/3.

[114] Which is the quantity of spectrum assigned in the auction in MHz.

is because the price paid will likely exceed the value of the second most valuable use (i.e., the value of the seller). The price agreed in trades would be a split of the differential between the buyer and the seller.[115]

5.3.1 Difficulties with using engineering cost models to estimate spectrum value

159. There are substantial difficulties in estimating the value of spectrum from engineering cost models. These issues related to:

   a. Difficulties in identifying and modelling the network operator that would determine the value of spectrum to the market;

   b. A wide range of assumptions that have a material impact on the estimated value of spectrum to an operator;

   c. The inherent variability in costs and hence the modelling providing a wide range of value estimates; and

   d. Modelling cannot take into account private information.

160. To estimate the value of spectrum we must model willingness to pay for spectrum of the network operator which will be the price setter. Broadly speaking for spectrum auctions, the spectrum is sold through the second-price mechanism, which means the highest bidder (winning) for a specific bandwidth will pay the amount bid by the second-highest bidder. In order to replicate this, spectrum modelling requires to take into account the valuation of spectrum of each participant. The modelling would only be consistent with the value from an auction if it reflected the value to the operator with the second-highest value from the spectrum.

161. Once an operator is selected as the appropriate benchmark, many assumptions are required to model the engineering value of the spectrum. The GSMA notes that a large number of factors could affect the spectrum pricing and it is difficult for business and particularly regulators to predict the price of the spectrum:[116]

> *Spectrum valuations are based on long-term business cases, involving assumptions about network deployment, and technical and commercial trends. Many of these assumptions are uncertain and subject to a variety of external risks, so valuations are typically subject to a wide margin of error.*

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115 In economic bargaining models, buyers and seller split the gains from trade, being the excess of the buyers valuation over the seller's valuation

116 GSMA, Effective Spectrum Pricing: Supporting better quality and more affordable mobile services, February 2017, https://www.gsma.com/spectrum/wp-content/uploads/2017/02/Effective-Spectrum-Pricing-Full-Web.pdf

> *Of course, **if it is difficult for a bidder to value a spectrum licence, it is even more difficult for a regulator to do so [emphasis added].***

162. Even if the assumptions are taken into account, the spectrum modelling may produce a wide range of estimate under different model set up. As an example, we have reviewed the modelling for the price of the 800MHz spectrum band in Australia by Plum Consulting, which is commissioned by the Department of Communication.[117] In Plum's analysis on the value of the 800MHz bands, two valuation approaches are adopted, the cost reduction valuation and the full enterprise valuation. The cost reduction valuation calculates the network cost saving arise from the use of an additional block of spectrum and use this value as network operators' willingness to pay for the spectrum. The full enterprise valuation approach calculates the net present value (NPV) of total business cashflows that a mobile operator will get from all the current spectrum holding.

163. The estimates of the value of the 800 MHz spectrum for the medium scenario varies significantly based on the model selection. The upper bound (full enterprise valuation) is at least 3 times the lower bound (cost reduction valuation), total spectrum prices could range from $438M to $1,428M.

Table 5-2: Plum's estimated cost of spectrum varies significantly ($/MHz/Pop)

Market scenario	Cost reduction value due to capacity provision	Full enterprise valuation
Low scenario	$0.00	$2.58
Medium scenario	$0.42	$3.16
High scenario	$0.87	$3.38
Scenario selected	**$0.87**	**$3.38**

Source: Plum. Note: The low, medium and high scenario depend on a number of factors such as population growth, ARPU growth, data usage growth etc.

164. Plum does not have a strong preference in the selection of the model. However, it excludes the upper bound (full enterprise valuation) for the only reason that the upper bound is not consistent with the international benchmarks:[118]

> *The modelling results give a wide range of values under the different market scenarios. Values at the upper end of the range are not plausible based on international benchmarks.*

117 Plum Consulting, Valuation of public mobile spectrum at 825-845 MHz and 870-890 MHz A report for the Department of Broadband Communications and the Digital Economy, 15 September 2011 https://www.communications.gov.au/file/18601/download?token=D2O3mz_l

118 Ibid.

165. Another issue with the engineering cost models is the availability of private information. In general, engineering cost models adopted by regulators often do not take into account potential business strategy and network designs that are confidential to the businesses, making it difficult to accurately measure the cost of operation[119]

> *… estimation of spectrum value by this approach* ***requires various crucial data from bidders, which include current business operation and network infrastructure [emphasis added]*** *owned along with data on investment of technologies that bidders plan to operate in their business.*

5.3.2 Spectrum trading also may not be reliable

166. In some markets, spectrum can, and is, traded in secondary markets. The price paid in secondary markets is likely to overestimate the opportunity cost of spectrum. This is because the price paid will likely exceed the value of the second most valuable use (i.e., the value of the seller). The price agreed in trades would be a split of the differential between the buyer and the seller.[120]

119 Mulisuwan, S., (2014). Estimation of Commercial Value of Spectrum: The Approach Adopted in Thailand. *Journal of Economics, Business and Management*, 2(2).

120 In economic bargaining models, buyers and seller split the gains from trade, being the excess of the buyer's valuation over the seller's valuation.

6 Unlocking the value of the broadcast spectrum

167. The amount of revenue realised from the assignment of 600 MHz spectrum to mobile would be an indicator of the value unlocked from the reallocation, but it is not the only indicator. Higher revenues from spectrum auctions are good indicators of success because they:

- show that spectrum has been allocated to a high value use as reflected in the bids received in the auction;
- would be consistent with a well-run auction, rather than an auction that has failed due to poor design that resulted in, say, strategic bidding;[121] and
- reduce the efficiency cost of raising Government revenue from alternative sources such as general taxation.[122]

168. The other key indicator that the value of the spectrum has been unlocked is in the timing of reallocation of the spectrum. The value of spectrum will be maximised when it is put to its highest value use. This would ideally be determined by testing whether the willingness to pay of potential spectrum users exceeds the willingness to accept of existing spectrum users, rather than through administrative determination.[123]

169. In this section we discuss the US Incentive Auction as best practice in unlocking the value of the 600 MHz spectrum both in terms of the value achieved and ensuring the efficient exchange of spectrum (i.e., when the buyer's willingness to pay exceeds the seller's willingness to accept). We adopt it as best practice in discussing aspects of this mechanism that could be adopted in the reassignment of the 600 MHz spectrum in Australia.

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121 Participants in auctions may engage in strategic bidding to lower the amount they pay or increase the amount competing bidders pay. The evidence indicates that strategic bidding is not uncommon in combinatorial clock auctions (CCA), with bids designed to inflate the price paid by other parties. Marsden, R., & Sorensen, S. (2017). Strategic Bidding in Combinatorial Clock Auctions – A Bidder Perspective. In M. Bichler & J. Goeree (Eds.), *Handbook of Spectrum Auction Design* (pp. 748-763). Cambridge: Cambridge University Press.

122 Morris, A. C. (2005). Spectrum auctions: Distortionary input tax or efficient revenue instrument?. Telecommunications Policy, 29(9-10), 687-709.

123 Spectrum trading may also be a tool to ensure that spectrum is used for its highest value purpose. There are barriers to trading spectrum, including coordination issues, that have meant that spectrum trading markets tend to be thinly traded.

6.1 The US Incentive Auction

170. The US Incentive Auction was held for the 600MHz spectrum in the US in April 2017. The auction in the US generated US$19.8 billion in gross revenue from 70 MHz of spectrum, which translates to AU$1.21/ MHz/Pop on average. Of the $19.8 billion in revenue generated, $10.05 billion paid to broadcasters and more than $7.3 billion was returned to the Government.[124]

171. While the US auctioned the 600MHz spectrum for 5G use the auction result are not directly comparable to Australia. In Australia, unlike the US, operators hold spectrum in both the 800 MHz and 900 MHz bands allocated to mobile broadband. In contrast, in the US, the 700 MHz and recently auctioned 600 MHz are primarily used for mobile services. An auction of the 700 MHz (698-806 MHz) band in the US was conducted in 2008 resulting in $19.5 billion for mobile services.[125]

172. Meanwhile, the spectrum in the 800 and 900 MHz bands are largely used for the fixed and land mobile, aeronautical and public safety services.[126] Around 50 MHz of spectrum in the 800 MHz band is used for mobile services. The FCC notes that:[127]

> *The Cellular Radiotelephone (Cellular) Service is in the 824 – 849 and 869 – 894 MHz spectrum range. The most common use of cellular spectrum is mobile voice and data services, including cell phone, text messaging, and Internet.*

173. The spectrum in the 900 MHz band is primarily used for fixed and land mobile services and not extensively used as commercial mobile services.[128]

174. The approach adopted by the Federal Communication Commission (FCC) in the US for the reallocation of the 600 MHz spectrum band was unique in that it used a market mechanism to reallocate spectrum. The US 600 MHz auction in 2019 consisted of two separate auctions:[129]

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124 FCC, 600MHz band, https://www.fcc.gov/wireless/bureau-divisions/broadband-division/600-mhz-band

125 FCC, Auction 73, https://www.fcc.gov/auction/73

126 FCC, Online Table of Frequency Allocations, February 2021 https://transition.fcc.gov/oet/spectrum/table/fcctable.pdf

127 FCC, 800 MHz Cellular Service, https://www.fcc.gov/wireless/bureau-divisions/mobility-division/800-mhz-cellular-service

128 FCC, Online Table of Frequency Allocations, February 2021 https://transition.fcc.gov/oet/spectrum/table/fcctable.pdf

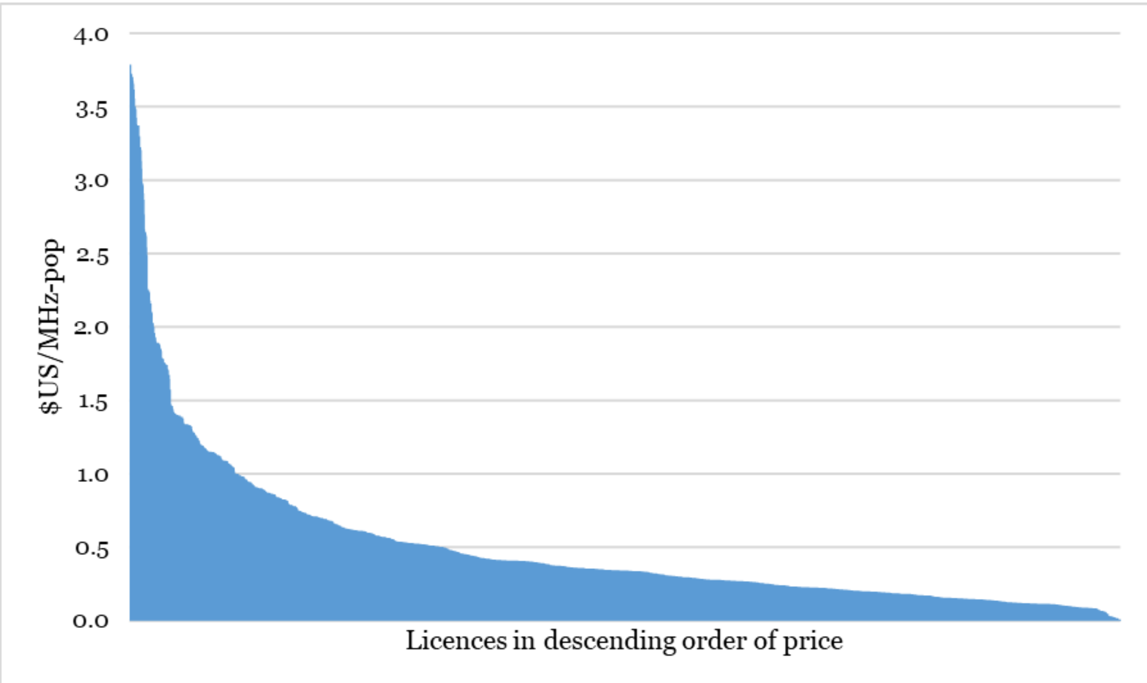
129 FCC, 600 MHz Band, April 2019. https://www.fcc.gov/wireless/bureau-divisions/broadband-division/600-mhz-band

- A reverse auction with existing broadcast television licence holders bidding to surrender their spectrum rights in return for payments. The reverse auction was designed to acquire enough licenses (spectrum) to clear a pre-determined amount of spectrum at a reasonable cost. This pre-determined amount was updated throughout the auction.
- A forward auction for flexible uses of the newly available auction after the broadcast television bands have been reorganised following the reverse auction.
- A coordination/ clearing rule to determine what quantities of licenses of each kind should be traded. The clearing/coordination rule ensured compatibility of the outcomes of the forward and reverse auctions and to achieve the revenue goals of the auction.

175. One particularly notable observation regarding the US auction is the high variability of prices/MHz/Pop across licences, as seen in the figure below that shows prices in descending order for licences. Despite the $1.21/MHz/Pop average price, approximately 68% of the licenses were sold at a price below $0.50/MHz/Pop and 89% were sold at a price below $1/MHz/Pop. The high average price is due to a small number of licenses that were sold for more than $3/MHz/Pop.

176. The large percentage of 600MHz licenses with low prices and large variance in the U.S. incentive auction suggests a high level of uncertainty in the expected future value of this spectrum band.

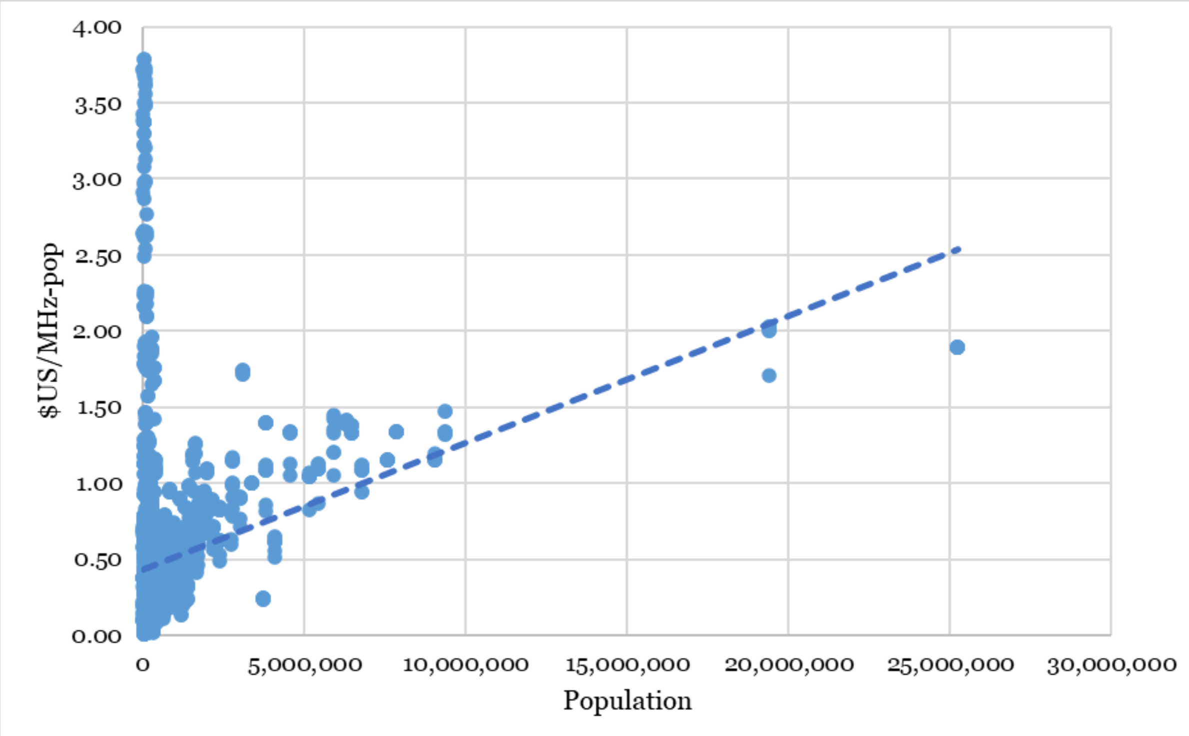
Figure 6-1: Distribution of prices paid across licences



Source: FCC, CEG analysis. Only includes licences with bidding credits attached.

177. The scatterplot in the figure below shows a positive correlation between the price paid for a licence and the population in its service area, although the relationship does not apply for service areas with very low population.

Figure 6-2: Scatterplot of licence price against population in the US



Source: FCC, CEG analysis. Only includes licences with bidding credits attached.

6.2 Market incentives in the assignment process

178. Prior to the 1990s, the process for assigning spectrum was largely administrative. It included so-called beauty contests as well as lotteries. It is beyond the scope of this paper to include advice in relation to the auction format or auction parameters that would maximise the value of any auction of the 600 MHz spectrum.

179. The timing of the spectrum reassignment is key to unlocking the value of the reassignment of the 600 MHz spectrum band. A reassignment that is "too early", will mean that commercial broadcasters incur wasteful expenditures on restacking, whilst the spectrum remains unused by mobile operators. A reassignment that is too late, will mean that incrementally higher value consumption of mobile broadband services will be delayed when it would be lower cost to restack the commercial broadcasts.

180. The value of spectrum, or any economic good for that matter, is determined based on the balance of supply and demand. Goods that are in high demand with limited

supply will have greater value than a good with high demand but a high level of supply. A high level of supply will reduce the relative scarcity of a good and hence its value will be lower, other things equal.

181. The essence of the Green Paper is a scheme in which commercial broadcasters are asked to voluntarily release spectrum in the 600MHz band in exchange for some relief in relation to licence fees and potentially content obligations. The proposal is unlikely to create strong incentives for the efficient release of spectrum relative to the potential value of the spectrum to mobile operators.[130]

182. In contrast to market mechanism for the reallocation of spectrum this approach decouples the value payment for the release of spectrum from the value of alternative uses. This decoupling would distort incentives for the efficient timing of a reallocation of the spectrum. Linking these payments would promote a more efficient allocation and unlock the value of the spectrum. The Green paper proposal therefore represents a continuation of the administrative approach to spectrum reallocation with its well understood drawbacks.[131]

183. The incentive auction is described by the Noble Prize winning economist who designed the auction in the following terms:[132]

> *A spectrum incentive auction is a market-based means of repurposing spectrum by **encouraging licensees to voluntarily relinquish spectrum usage rights in exchange for a share of the proceeds from an auction of new licences to use the repurposed spectrum**. The incentive auction combines a reverse auction, in which incumbents bid to relinquish their spectrum usage rights; a forward auction, in which buyers bid to acquire the relinquished spectrum for new purposes; and a procedure to reconcile the two. [emphasis added]*

184. The applicability of the US incentive auction to Australia is questionable. This in large part due to the differences in the broadcasting industries in each country. The 'problem' the US incentive auction was trying to solve was the release of spectrum owned by a large number of independent, regional, commercial, and the not-for-profit broadcasters. This is not the case in Australia where there are a relatively small number of broadcasters.

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130 Television broadcasters currently pay around $40 million in spectrum fees annually. This compares to spectrum that could be worth up to $1 billion to mobile operators.

131 Hazlett, Thomas, W. 2008. "Optimal Abolition of FCC Spectrum Allocation." Journal of Economic Perspectives, 22 (1): 103-128.

132 Symons, H. and Milgrom (2018) "Lessons from the US Incentive Auction", Vol 45 Issue 4, InterMEDIA, pp 25-29.

185. In addition, the pervasive delivery of terrestrial broadcasts for television in Australia creates significant continuity of service issues.[133] In the US, only around 15% of households receive terrestrial transmission of television.[134]

186. Nevertheless, a mechanism in which to test the willingness to accept payments for the release of spectrum against the willingness to pay for spectrum, would be step forward for economic efficiency and avoid arbitrary decision making with the risk of regulatory error. For example, allowing commercial broadcasters to share in the proceeds of the auction would create a more market-based outcome.

187. A mechanism that created incentives for broadcasters and MNOs to reveal their true valuations of the spectrum would be desirable from an efficiency perspective. It would reduce the need to rely on non-market assessments of the value of spectrum to each party. As discussed, market-based outcomes could be considered as an alternative to administrative alternatives as they have the potential to deliver more efficient outcomes, including the amount and timing of the spectrum assignment driven by the relative value of alternative uses rather than administrative fiat or unrelated rewards and penalties.

133 The public service broadcasters in Australia (ABC and SBS) are an additional consideration in applying the incentive auction scheme to Australia.

134 Ofrcom, Communications Market Report 2016: International, December 2016. Available at www.ofcom.org.uk/research-and-data/multi-sector-research/cmr/cmr16/international

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Appendix A Regression literature

188. The empirical literature that investigates the determinants of spectrum prices generally include a proxy to control for the volume of spectrum supplied that is available in the auction. There have been two approaches to construct the proxy:

- one approach is to use the ratio between the number of licenses available in the auction against the number of bidders; and
- another approach is to include the variable, the total bandwidth of spectrum available in the auction, in the regression as a separate variable from the number of bidders.

189. Almost all of the literature finds that an increase in spectrum supply leads to a decrease in the winning bid. Madden and Suenaga (2016) has found if the number of licenses decrease, while holding the number of bidders the same, it would lead to an increase in price: [135]

> *… auction theory conjecture that more intense competition among bidders places upward pressure on prices is supported*

where competition is measured using the ratio between the number of bidders and number of licenses available.

190. Martinez-Cid and Jiao (2017), which uses the bandwidth of spectrum of available, also finds that an increase in the available bandwidth leads to a decrease in price: [136]

> *The total amount of spectrum offered in the auction lowers the price of spectrum, which matches our intuition that this represents a new, increased supply of spectrum.*

191. Other economic literature that has found similar results include Bohlin, Madden and Morey (2010)[137], Madden, Saglam and Morey (2010)[138] and dotEcon (2012).[139]

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135 Madden and Suenaga (2016)[135], The determinants of price in 3G spectrum auctions, Applied Economics DOI: 10.1080/00036846.2016.1254342

136 Martinez-Cid and Jiao (2017) "A Brief Review and Analysis of Spectrum Auctions in Canada," Working paper

137 Bohlin, Madden and Morey (2010), An Econometric Analysis of 3G Auction Spectrum Valuations. Working paper

138 Madden, Saglam and Morey (2010), Auction design and the success of national 3G spectrum auctions. Working paper

139 dotEcon (2012), Award of 800MHz, 900MHz and 1800MHz – Fifth Benchmarking report – A report for ComReg, ComReg document 12/23

Appendix B The 850/900 MHz spectrum

192. This appendix discusses the competition limits for the 850/900 MHz spectrum auction.

B.1 Spectrum guarantee and competition limits: the draft decision of the Minister

193. The Minister has published the Exposure Draft instrument proposing a competition limit of 82 MHz:[140]

> *The intent of the 82 MHz limit is to prevent monopolisation of spectrum licences in the sub1 GHz band, partially addressing the disparity in sub-1 GHz band spectrum licence holdings between MNOs, whilst enabling competition between MNOs, and any other bidders. This limit will enable the three national MNOs—Optus, Telstra and TPG Telecom—to acquire further spectrum below sub-1 GHz, but will prevent any one MNO from using more than 40% of spectrum-licensed spectrum in the sub-1 GHz band*

194. The Minister also sets out the reason for the additional 2 MHz of spectrum allowed. The additional 2 MHz of spectrum would not enable any MNOs to acquire more lots than the limit of 80 MHz:

> *2 MHz has been added to the recommended limit to account for the fact that 2 MHz of 'downshift' spectrum will be allocated to the winner of the lowest lot in the 900 MHz band. The downshift spectrum will facilitate a 1 MHz downshift of spectrum holdings in the adjacent 850 MHz band to align with internationally harmonised frequency ranges. It will also enable full utility of the lowest 900 MHz lot by removing the need for a 1 MHz guard band. An 82 MHz limit will not enable bidders to acquire any more lots at the 850/900 MHz auction than an 80 MHz limit would have.*

195. The spectrum limit is applied for both metropolitan area and regional area.

> *That is, a person, or relevant group of persons, may use up to 82 MHz of spectrum under spectrum licences in the metropolitan area and regional area, but cannot use more than 82 MHz of spectrum under spectrum licences in either area. The intent of the 82 MHz limit is to prevent monopolisation of spectrum-licensed spectrum in the sub-1 GHz band and*

140 Radiocommunications (Spectrum Licence Limits—850/900 MHz Band) Direction 2021, 27 April 2021, https://www.communications.gov.au/have-your-say/850900-mhz-auction-allocation-limits-exposure-draft

partially address the disparity in sub-1 GHz band spectrum-licensed holdings between MNOs.

196. If the Final Determination retains the same settings as the Exposure Draft, Minister has effectively set out a guarantee for 10MHz for TPG and Optus respectively in the paired bands of 895 to 915 MHz and 940 to 960 MHz. 40 MHz of spectrum will become available in the relevant bands. No one can acquire more than 20MHz of the spectrum other than TPG and Optus in these bands.

B.2 Spectrum allocation limit: the advice from the ACCC

197. The ACCC consider that imposing a limit on the amount that each carrier can bid for would promote competition. In cases where there is excessive and unconstrained spectrum in the market, bidders may bid more than they need in order to prevent others from accessing it.

198. A consultation paper previously published by the ACCC also indicates that the design of the 850/900MHz spectrum auction could include the condition on current spectrum holdings by Telstra, Optus and TPG (Vodafone).

199. The ACCC has advised the Minister for Communications on the allocation limits for the 850/900 MHz spectrum allocation.[141] The ACCC advises that for sub-1GHz band, an allocation limit of 80MHz should be imposed for any of the MNOs:

> *… an allocation limit should be imposed for the 850/900 MHz allocation, such that no person or specified group of persons could hold more than 40 per cent, or 80 MHz, of all sub-1 GHz band spectrum available for use as a result of the 850/900 MHz allocation,* ☐

200. The ACCC further recommend that no basis for an allocation guarantee for Telstra in the 850/900MHz band.

> *there are no grounds to guarantee spectrum for Telstra in the 850/900 MHz allocation for the purpose of supporting continuity of services, and the recommended allocation limit would provide a reasonable opportunity for Optus and TPG to acquire spectrum in the 900 MHz band in the absence of any spectrum guarantee.*

201. For Optus specifically, the ACCC recognise that there is a risk that Optus may have sufficient spectrum available to roll out 5G nationally, which would adversely affect competition and detriment customers.

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141 ACCC, Allocation limits advice for the 850/900 MHz spectrum allocation Public version March 2021, https://www.accc.gov.au/system/files/ACCC%20advice%20to%20the%20Minister%20on%20allocation%20limits%20for%20the%20850_900%20MHz%20allocation%20March%202021.pdf

The ACCC considers that the key competition issue arising from this allocation is Optus' lack of sub-1 GHz spectrum compared to the other MNOs. Optus' ability to compete effectively in the mobile services market will likely be constrained if it does not acquire more sub-1 GHz band spectrum in the 850/900 MHz allocation. In particular, there is a risk that Optus may not be able to roll out 5G technology widely and efficiently in Australia in the absence of more sub-1 GHz spectrum. This would adversely affect competition in the mobile services market, particularly in regional areas by limiting the deployment of competitive 5G networks by all MNOs across Australia, to the detriment of consumers. The ACCC has not found that Telstra or TPG face similar spectrum constraints.

202. The ACCC considers that the 80 MHz limit will provide the opportunity for Optus to acquire the spectrum it needs for an effective competition.

The ACCC considers that the recommended limit will provide a reasonable opportunity for Optus to acquire the spectrum it needs to compete effectively in the mobile services market in the medium to long term, but does not prevent Telstra and TPG from participating in a potential price-based allocation. In doing so, the recommended allocation limit will promote competition and investment in the mobile services market, including in regional Australia and support the deployment of 4G and 5G technologies to the benefit of consumers

203. The ACCC considers that Optus and TPG has strong incentive to refarm the 3G spectrum for 5G use, even if it is being used for 3G at this stage:

The ACCC considers that Optus' and TPG's spectrum requirements for the continued operation of their 3G networks is relevant in the short term. Optus and TPG will likely have strong incentives to refarm any spectrum acquired at the 850/900 MHz allocation for 5G use, even if it is intended for 3G use in the first instance.

204. The discussion focuses on the design of the auction to achieve a competitive outcome and resolve competition imbalance. The discussion and submission have not included the topic regarding whether to release the 600 MHz spectrum early, which compensates all the MNOs.

B.3 View from the ACMA

205. The ACMA have stated a view that the spectrum should be allocated in 5 MHz paired lots:

We remain of the view that the current configuration is not conducive to optimally efficient carriage of 4G or 5G services, and reconfiguration of the band into 5 MHz paired lots represents the most efficient configuration for

> *the band. 5 MHz paired lots would provide flexibility for bidders to obtain small quantities of spectrum and would enable consolidation into larger holdings if desired. The addition of the 2 x 1 MHz of spectrum attached to the lower 900 MHz lot will potentially assist negotiations between the licensee of the lower 900 MHz lot and adjacent 850 MHz band spectrum licensees (frequency ranges 825–845 MHz and 870–890 MHz) to achieve a timely downshift of the 850 MHz spectrum licences and therefore increase the usability of the lower segment in the 900 MHZ band.*

206. The ACMA also indicate that the spectrum should be licensed for a term of 15 years.

Appendix C Comparing price per MHz per Pop

207. The methodology for obtaining the price per MHz per population, adjusted licence duration to 15 years, involves the following steps:

i. Collect and calculate the total amount raised for each spectrum band in domestic currency. This is collected from regulators and industry bodies.

ii. Convert the total amount raised from the year of the auction to 2018 term using the inflation rate adjustment factor for each country from the World Bank.

iii. The purchasing power parity (PPP) from the World Bank index the United States as 1. We convert the PPP to Australian terms by dividing each country's PPP factor in 2018 by 1.5 (which is Australia's PPP conversion factor in 2018).

iv. Divide the total amount raised in step (ii) by the value calculated in step (iii) for the relevant currency. This produces the total amount raised for each spectrum band in Australian dollar terms.

v. Divide step (iv) by the amount of spectrum sold to obtain the amount raised per MHz in Australian dollar terms.

vi. Calculate the license duration adjustment factor using the following formula, which accounts for the different lengths in the licence terms by adjusting them to a 15 year duration:

a. $\sum_{t=0}^{179}\left(\frac{1}{(1+WACC)}\right)^{t} \Big/ \sum_{t=0}^{T-1}\left(\frac{1}{(1+WACC)}\right)^{t}$

The formula is based on the formula used by Ofcom, who assumed an annual post-tax real WACC of 4.7%, which we also used.[142] T is the duration of the licence in months.

vii. Multiply step (v) by step (vi) to obtain the adjusted amount raised per MHz in Australian dollar terms.

viii. Divide step (vii) by the population of the respective country to obtain the adjusted amount raised per MHz per population in Australian dollar terms.

[142] Ofcom, "Annual licence fees for 900 MHz and 1800 MHz spectrum", Appendix 7, August 2014, pg 55, available online at http://stakeholders.ofcom.org.uk/binaries/consultations/annual-licence-fees-900-MHz-1800-MHz/annexes/Annexes_1-7.pdf.

Appendix D Spectrum holding by MNOs

Table 6-1: Current sub-1GHz spectrum holding by MNO

Country	Operator	700	800	900	Total
Denmark	TDC	30	40	20	90
Australia	Telstra	40	20	16.8	76.8
United Kingdom	O2	20	20	34.8	74.8
Norway	Telenor	20	20	30.2	70.2
Germany	Telekom	20	20	30	70
Iceland	Vodafone Iceland	0	40	30	70
New Zealand	Spark	40	30	0	70
Iceland	Siminn	40	0	29.6	69.6
Norway	Telia	20	20	29.6	69.6
Australia	TPG	30	20	16.4	66.4
Czech Republic	O2 (PPF)	20	20	24.8	64.8
Czech Republic	T-Mobile	20	20	24.8	64.8
Finland	DNA	20	20	23.2	63.2
Finland	Elisa	20	20	22.8	62.8
Finland	Telia	20	20	22.8	62.8
New Zealand	Vodafone New Zealand	30	0	30.4	60.4
Czech Republic	Vodafone	20	20	20	60
Germany	O2	20	20	20	60
Germany	Vodafone	20	20	20	60
Sweden	Telia	20	20	20	60
Italy	TIM	20	20	19.6	59.6
Italy	Vodafone	20	20	19.2	59.2
France	Orange	20	20	17.4	57.4
United Kingdom	Vodafone	0	20	34.8	54.8
Norway	ice	20	20	10.2	50.2
Denmark	3 (H3G)	20	0	30	50
Greece	Vodafone	0	20	30	50
France	Bouygues	10	20	19.6	49.6
Spain	Movistar	0	20	29.6	49.6
France	SFR	10	20	17.4	47.4
Belgium	Proximus	0	20	24.8	44.8
Belgium	Orange	0	20	23.2	43.2
Belgium	Base	0	20	20.4	40.4
Greece	Cosmote	0	20	20	40
Greece	Wind Hellas	0	20	20	40
Portugal	Vodafone	0	20	20	40
Spain	Orange	0	20	20	40

Spain	Vodafone	0	20	20	40
New Zealand	2 Degrees	20	0	19.6	39.6
Italy	Wind Tre	0	20	19.2	39.2
Australia	Optus	20	0	16.8	36.8
Portugal	MEO	0	20	16	36
Portugal	NOS	0	20	15.6	35.6
France	Free	20	0	15.2	35.2
Iceland	Nova	0	20	10	30
Italy	iliad	20	0	10	30
Sweden	Tre	0	20	10	30
United Kingdom	3 (three)	20	10	0	30
United Kingdom	EE	20	10	0	30
Sweden	Tele2	0	0	18	18
Sweden	Telenor	0	0	10	10

Source: Spectrum Monitoring. CEG analysis. Note: For Australian MNOs, we show the spectrum holding for metro area only. The spectrum in the 900 MHz band is subject to reallocation for Australian MNOs. We have not included MNOs without spectrum holding in the sub-1GHz band in the table.

Appendix E Data sources

208. This section sets out the data source of spectrum prices.

Figure E-1: Spectrum auction data source

Country	Year	Primary source
Australia	2013	https://www.acma.gov.au/auction-summary-700-mhz-digital-dividend-and-25-ghz-band-reallocation-2013
Australia	2017	https://www.acma.gov.au/auction-summary-700-mhz-residual-lots-2017
Belgium	2013	https://www.bipt.be/consumers/publication/bipt-makes-the-results-of-the-800-mhz-auction-public
Canada	2014	https://www.ic.gc.ca/eic/site/smt-gst.nsf/eng/h_sf10598.html
Canada	2019	https://www.ic.gc.ca/eic/site/smt-gst.nsf/eng/h_sf11331.html
Czech Republic	2013	https://www.ctu.cz/tiskova-zprava-kmitocty-pro-site-lte-v-aukci-vydrazeny
Czech Republic	2020	https://www.ctu.cz/sites/default/files/obsah/ctu/telekomunikacni-vestnik-castka-08/2020/obrazky/tv-2020-08.pdf
Denmark	2012	https://web.archive.org/web/20140709162458/http://danishbusinessauthority.dk/800-mhz-auction
Finland	2013	https://www.lvm.fi/en/-/spectrum-auction-results-4g-spectrum-to-dna-elisa-and-teliasonera-792236
Finland	2016	https://www.lvm.fi/-/700-mhz-spectrum-to-dna-elisa-and-teliasonera-913011
France	2011	https://en.arcep.fr/news/press-releases/view/n/arcep-publishes-the-results-of-the-allocation-procedure-for-4g-mobile-licences-in-the-800-mhz-band-the-digital-dividend.html
France	2015	https://en.arcep.fr/news/press-releases/view/n/final-results-of-the-allocation-procedure.html
Germany	2010	https://www.bundesnetzagentur.de/SharedDocs/Downloads/EN/Areas/Telecommunications/Companies/TelecomRegulation/FrequencyManagement/ElectronicCommunicationsServices/FrequencyAward2010/PresentationOutcomeAuction101015.pdf;jsessionid=D659B0BAA92AAE64E108665E610A1AC3?__blob=publicationFile&v=2
Germany	2015	https://www.bundesnetzagentur.de/SharedDocs/Downloads/EN/Areas/Telecommunications/Companies/TelecomRegulation/FrequencyManagement/ElectronicCommunicationsServices/DecisionP2016_pdf.pdf;jsessionid=AFFDF9C8B398D574F9E5194462177D7F?__blob=publicationFile&v=3
Greece	2011	https://www.telegeography.com/products/commsupdate/articles/2011/11/15/three-cellcos-pay-eur380-5m-for-900mhz-1800mhz-frequencies/
Greece	2014	https://www.eett.gr/opencms/export/sites/default/admin/downloads/News/Auction_results_eng.pdf
Iceland	2017	https://www.commsupdate.com/articles/2017/06/02/iceland-concludes-auction-for-lte-spectrum-in-four-bands/
Italy	2011	https://www.mise.gov.it/images/stories/documenti/SGUS_t469.pdf
Italy	2018	https://www.mise.gov.it/images/stories/documenti/Determina_Direttoriale_aggiudicazione-FIRMATA.pdf
New Zealand	2014	https://www.rsm.govt.nz/projects-and-auctions/auctions/completed-spectrum-auctions-1996-present/auction-12/

Norway	2017	https://www.dotecon.com/news/nkom-announces-900-mhz-auction-results/
Portugal	2011	https://www.anacom.pt/render.jsp?contentId=1106646
Spain	2011	https://www.mincotur.gob.es/en-US/GabinetePrensa/NotasPrensa/2011/Paginas/npfinaizacionsubasta010811.aspx
Sweden	2011	https://www.pts.se/en/english-b/radio/auctions/licences-in-the-800-mhz-band/
Sweden	2018	https://www.pts.se/en/english-b/radio/auctions/700/
United Kingdom	2013	https://www.ofcom.org.uk/__data/assets/pdf_file/0025/92446/Final-results-of-the-800-MHz-and-2.6GHz-4G-auction.pdf
United Kingdom	2020	https://www.ofcom.org.uk/spectrum/spectrum-management/spectrum-awards/awards-in-progress/700-mhz-and-3.6-3.8-ghz-auction
United States	2017	https://www.fcc.gov/wireless/bureau-divisions/broadband-division/600-mhz-band#:~:text=The%20initial%20600%20MHz%20licenses