(c o v e c)
covec limited
112 bush rd po box 300107 albany auckland new zealand
t +64 9 916 1970 f +64 9 916 1971 www.covec.co.nz

Development of Price Setting Formulae for Commercial Spectrum Rights at Expiry

for

The Ministry of Economic Development

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(covec)

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Executive Summary

Various time-limited rights to use and manage spectrum have been created and sold by the New Zealand Government over the last thirteen years. The main uses of these rights have been to provide radio, television, and cellular telephony services. In general, these rights have a life of 20 years, and the first rights are due to expire in 2010. To provide certainty and promote investment and innovation, the government has recently decided to offer renewal options to right-holders, five years ahead of the expiry dates. These offers are to be priced using transparent formulae, and in the event that the offers are rejected the spectrum rights will be auctioned.

Covec has been commissioned to develop the formulae on which this regime will be based. This report provides our analysis of the issues involved in setting the formulae and the formulae themselves.

A reasonable degree of technological change is expected in spectrum-related industries over the next ten to twenty years. While we have attempted to accommodate and embody these changes throughout this report, it is impossible to accurately predict their exact timing and impacts. The results presented in this paper therefore need to be considered in this context. They represent our best estimate of the future value of spectrum licences in an environment that is subject to a high degree of complexity and even greater uncertainty.

Our general approach is to seek adjustment factors that relate the original price paid for a spectrum right or license to its value at the time of renewal. The original price paid is either determined from the initial spectrum auctions, or, in the case of licenses awarded to incumbents is the price paid by the incumbent.

The adjustment factors are designed to update the base prices, and incorporate information on the past and expected future trends in revenues and costs in the industry using the spectrum. The basic idea is to forecast the future cashflows of the business using the spectrum over the period for which the renewed right or license will be valid and then translate these into appropriate adjustment factors.

Even though forecasts of net cashflow may have revealed some variation in growth from one year to the next, we made the initial assumption that a constant (average) growth rate should be used. This significantly simplified the algebra underlying the formulae without any real loss of generality and without introducing any significant error to the final results.

Next, we observed that net cashflow in any given period is a complex and non-linear function of revenue and cost growth, as well as the initial values that are assumed for revenues and costs. We also noted that profit margins steadily increase or decrease over time if revenue and cost growth rates differ. To avoid this possibility, we made the further assumption that revenues and costs grow at the same rate. This ensured that profit margins are constant over time and meant that we need only estimate revenue growth or cost growth to derive the annual growth in net cashflow.

Based on preliminary research, and in agreement with MED, we found that estimates of revenue growth were more reliable than those of cost growth. Consequently, we used forecasts of revenue growth to estimate the growth rate of net cash flows. For the radio and television industries, this meant deriving econometric models that could accurately forecast future advertising revenues for each industry. We found that accurate forecasts could be derived from models that related industry advertising revenues to population. Using these models along with Statistics New Zealand's medium population projections, we inferred growth rates for industry advertising revenues separately for television and radio. These were then used to derive the final pricing formulae for licences that relate to these industries.

Valuing cellular spectrum is complicated by the fact that, unlike radio and television, the cellular industry is not yet mature. In addition, future technological changes are likely to have a bigger impact on the cellular industry. We therefore discuss two alternative approaches to valuing cellular spectrum. The first is a formulaic approach similar to that used for radio and television. This approach has the advantages that it is simple to implement and is highly transparent, but is hampered by relatively short data series. This approach also does not explicitly account for technological changes. The alternative approach is to conduct a more detailed valuation exercise in consultation with the firms in the industry. This approach lacks transparency and simplicity compared to the formulaic approach but it is more flexible. In addition, such an approach may take better account of changes in industry expectations with regards to future cashflows.

The approach used for multipoint distribution services (MDS) licenses is also slightly different to that for radio and television, due to data constraints. We use a PPI Output index for communications services to estimate revenue growth, and maintain the other assumptions that allow us to relate this to growth in cashflows. Finally, we outline the general steps required to apply the general formula to other spectrum licences, such as Distributed Music Services (DMS).

Most original and renewed licenses are for a period of 20 years. However, the renewal price formulas that we develop are quite flexible in that they can be readily adjusted to cover cases where either the original or renewal periods (or both) are for periods other than 20 years. We also provide formulae that allow for the renewal fee to be paid as a lump-sum (five years prior to renewal), or as an annual fee during the renewal period.

In this report, we also consider some other important issues. First, since our renewal prices are heavily dependant on the original prices that were paid, we discuss the observed heterogeneity in these prices and whether any adjustments should be made to the base prices. We consider two forms of adjustment: averaging of base prices, and introducing 'reserve' prices into the renewal formula. We discuss the advantages and disadvantages of both of these approaches in the context of the Crown's policy and economic efficiency. However, by agreement with the Ministry of Economic Development, a recommendation on the adoption of either of these methodologies lies outside the scope of this report.

We also provide some guidance as to the appropriate discount rate to be employed in the cashflow calculations. In our example calculations, we have assumed that an appropriate WACC for the relevant industries is around 11%.

Throughout this report, we provide an example renewal price calculation for each type of license, using the formulas that we have developed. The following table summarises these examples.

License Type	Original Price	Value at date of expiry	Renewal Price (paid 5 years in advance)
Auckland UHF-TV	$100,000	$225,422	$133,777
Wellington FM Radio	$25,000	$29,506	$17,510
National Cellular*	$10,000,000	$12,373,171	$7,342,875
National MDS	$100,000	$72,280	$42,895

* Cellular figures based on the formulaic valuation methodology.

1. Context

Radio spectrum in New Zealand is managed under the Radiocommunications Act 1989 ('the Act') by the Ministry of Economic Development on behalf of the Crown. Amongst other things, the Act provides for the creation of tradable, fixed term rights over parts of the radio spectrum. Spectrum rights are essentially property rights in the sense that they have legal certainty, are tradable and can be mortgaged.[1]

At the broadest level there are two tiers of spectrum rights:

- Management Rights - an exclusive right over a nation-wide frequency band, for up to 20 years, to grant spectrum licences to frequencies within that band; and

- Spectrum Licences - the right to transmit radio signals within a defined part of the band specified in a management right.

For the purposes of this report, the terms spectrum rights and spectrum licenses will be used interchangeably.

Since 1989, the Crown has gradually created management rights and spectrum licences for a range of different types of spectrum. The Crown has retained management rights in respect of spectrum suitable for broadcasting, perhaps due to the public good nature of such services, and has therefore allocated spectrum licences only. Spectrum suitable for telecommunications is held by way of management rights – the majority of which are held privately.

Spectrum rights created under the Act start to expire from 2010 onwards, beginning with spectrum licences for UHF television. However the Act is silent as to how rights should be reallocated once they expire, other than that they revert to the Crown. The Crown is nevertheless able to create a "succeeding" management right ahead of expiry for the purpose of ensuring a seamless transition from one term to another.

A lack of certainty for right-holders and other industry stakeholders regarding the policy for dealing with spectrum rights once they expire can have a

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[1] Material in this section has been abridged from the following web page: http://www.med.govt.nz/pbt/rad_spec/rights-at-expiry/background.html

negative impact on economic growth and innovation. For example, some investment in assets that are complementary to spectrum is likely to be deterred as the expiry date approaches if this uncertainty persists.

Consequently, Cabinet recently set a policy whereby existing right-holders would have the option to renew rights five years prior to expiry for a price based on price-setting formulae that estimate the market value of the rights. Since the Act does not prescribe a method for calculating these renewal prices, a research project was initiated to derive a suitable formula.

Covec was commissioned by the Ministry of Economic Development to develop formulae for establishing spectrum right renewal prices. Following the completion of this research, which includes peer review and consultation phases, these formulae will be used to set prices at which incumbent spectrum right holders will be able to renew their rights. In the event that these prices are rejected by right-holders, the rights will be re-auctioned.

2. Current Uses of Spectrum

Since the introduction of the Radiocommunications Act 1989, commercial management rights and spectrum licences have been issued for a number of different uses. Table 1 summarises the main categories of use along with whether management rights and spectrum licences are privately held or crown owned, and also the year in which these rights and licences expire.

This project is primarily focussed on spectrum rights due to expire up to and including 2015.

Table 1 Current Allocation of Spectrum.

Service	Management Right	Spectrum Licenses	Date of Expiry
UHF Television	Crown owned	Privately held	2010
General (MDS)	Privately held	Privately held	2010
AM Radio	Crown owned	Privately held	2011
FM Radio	Crown owned	Privately held	2011
Cellular Telephone (GSM - A)	Privately held	Privately held	2011
Cellular Telephone (GSM)	Privately held	Privately held	2011
Cellular Telephone (GSM - A)	Privately held	Privately held	2012
Cellular Telephone (AMPS)	Privately held	Privately held	2012
Cellular Telephone (GSM)	Privately held	Privately held	2012
VHF Television	Crown owned	Privately held	2015
LMDS	Privately held	Privately held	2018
Cellular and Fixed (2 GHz band)	Privately held	Privately held	2021
Cellular 900 MHz	Privately held	Privately held	2022
WLL	Crown owned and Privately held	Privately held	2022
LMDS	Privately held	Privately held	2022

Source: Ministry of Economic Development.

3. Future of Spectrum and New Technologies

One way to interpret the objective of this research is that, for each right, we seek a formula that results in a reasonable approximation to a fair market value of a spectrum right covering the 20 year period from the date at which the existing rights expire. Such a value will clearly depend on the expectations of potential right-holders of the earning potential that would be conferred by the right. It therefore also depends on the way the market expects to be able to use the spectrum.

In this section we outline some possible scenarios for the future use of radio spectrum in New Zealand, most of which stem from rapid technological change. These changes, and uncertainty surrounding their timing and impact, highlight the difficulty of valuing spectrum rights over such distant time horizons, as required in this project.

An attempt to predict future spectrum technology and market trends for the period 2001 to 2011 was made by the MED in 2001.[2] The results, which we have confirmed and updated with developments since 2001, are presented here for technologies that use the spectrum of interest to this project, namely: cellular telephony, radio, television and multipoint distribution service (MDS).

3.1. Cellular Telecommunications

The future state of the mobile telecommunications market in New Zealand will be determined largely by the evolution of the market structure and the development and deployment of mobile technology. In this section we discuss the possible future scenarios for these two factors.

With regard to market structure, there is a possibility of future entry into the mobile telecommunications market. Both TelstraClear and Econet Wireless have management rights to unused cellular spectrum. However, the capital cost of any new entry will be very significant and coupled with the total market size, is likely to reduce the threat of entry for the existing operators. On the other hand, a new cellular operator may be able to rent capacity on an existing operator's network. Nevertheless, given the uncertainty about future entry, our modelling in section 6 below assumes that the level of competitiveness in the market remains unchanged.

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[2] *Future Spectrum Usage - A Forecast of Technical Issues for the Periods: 2001-2006, 2006-2011*, Ministry of Economic Development, 2001.

Technological changes are likely to have the biggest impact on the cellular industry in the future. For example, the introduction of third-generation cellular services (in particular, high-speed data services) that can operate using the 2GHz frequency range is likely to have a significant impact on the usage and value of current first and second-generation services (voice and text messaging services) that operate around the 900MHz frequency range. Third generation (3G) services can use any of several technologies including UTMS or Wide-Band CDMA, CDMA EV-DO and CDMA EV-DV, all of which permit the delivery of high potential value services such as mobile videoconferencing, advanced video games, and high speed data and internet access.

Moving towards 2006 there is a general expectation that we will see the transition from first generation (1G) to second generation (2G) cellular service completed, the rollout of two and a half generation (2.5G) services well advanced, and third generation services underway. The third generation represents a significant shift from the current first and second-generation technologies and is therefore expected to have an impact on the value of second-generation spectrum.

Offsetting this is the fact that third-generation services can also be provided using the existing 1G/2G spectrum (subject to some constraints) and that voice and text messaging services are likely to continue to be provided using 1G/2G spectrum.

Planning for the fourth generation (4G) technology is expected near 2011. We may also see the development of High-Altitude Platform Systems (HAPS)[3] to augment the cellular network sometime between 2006 and 2011.

Convergence of technologies may also become a significant driver in cellular development towards 2011 and a number of key technologies are being developed internationally:[4]

- Software Defined Radio (SDR)
- Internet Protocol over wireless systems
- Terrestrial Wireless Interactive Multi-media Systems

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3 HAPS are data systems that reside onboard airplanes or airships in the earth's stratosphere. These systems provide high bandwidth at lower cost than satellite-based systems.

4 A full assessment of the potential impact of convergence is beyond the scope of this report.

These additional features will not require further frequency allocations and they are therefore a potential benefit to incumbent holders of spectrum rights in the relevant frequencies.

Convergence, along with rapid technology advancement, is expected to see industry growth continue to be significant. For example, The Yankee Group forecasts global cellular subscriber revenue to grow from US$387 billion in 2002 to US$584 billion in 2007, making wireless services similar in value to worldwide crude oil production.[5]

To the extent possible, these impending technological changes should be taken into account by any methodology that attempts to estimate the value at expiry of current cellular spectrum licenses. In section 6 we develop such a model and calibrate it using the historical growth of cellular usage. We then use this model to predict the value at expiry of the current licenses.

3.2. Radio

3.2.1. Amplitude Modulation (AM):

The AM broadcasting band in New Zealand is very heavily used and the possibility for new frequencies is virtually exhausted. While some expansion for existing networks is possible using techniques like directional antennae, it is expected that the number of transmitters will stay the same or decrease.

Until 2006, existing services are likely to continue. We expect that there will be some transfer to FM broadcasting but that there will be continued demand for AM.

The period from 2006 to 2011 could see the introduction of digital AM transmissions for testing and development purposes, but progress here is likely to be slow, because of interference externalities and the fact that changing the basic properties of the AM spectrum requires international consensus. Digital technologies are not backwards compatible with existing technology, so a changeover would necessitate long time frames, during which simultaneous analogue and digital broadcasting would be required.

[5]http://www.yankeegroup.com/public/news_releases/news_release_detail.jsp?ID=PressReleases/news_06-24-2003_corporate.htm

As the existing AM band is full, digital transmission may need more bandwidth than what is available and New Zealand might need to follow other jurisdictions, such as the Americas, the Philippines and Sri Lanka, by providing for Broadcasting in the band 1612-1705 kHz.

3.2.2. Frequency Modulation (FM):

Until 2006, very heavy demand with intense competition for new frequencies is expected for FM radio. To meet this demand the 100-108 MHz band has been cleared and partially reallocated, with priority given to government funded radio.

According to the MED's spectrum planning division,[6] from 2006 to 2011 there are likely to be large numbers of transactions for relocating and modifying existing licenses, with continued high demand for access to FM frequencies for the main population centres.

Given the inertia of having an estimated 5 million radio receivers in everyday use and as there is little international pressure for a transition to digital services, continued analogue operations are expected for this decade.

Some value-added services like SDR may come into existence for GPS correction or other low data rate applications.[7]

3.2.3. Digital Radio

Digital audio broadcasting (DAB) at VHF and 1.4 GHz frequencies is beginning to be implemented in some countries. However the uptake has been very slow and high demand is not expected until reasonably priced receivers are readily available.

DAB satellite services are operational with the Worldspace Satellite Network but this does not cover New Zealand. There would appear to be limited interest in the satellite delivery of DAB services to New Zealand apart from those services that "piggyback" on satellite-provided television services.

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[6] Future Spectrum Usage (2001), p 38.

[7] Software Defined Radio is an architecture that allows compatibility between various radio technologies and more efficient use of spectrum.

In New Zealand, VHF spectrum is already used by analogue TV and radio broadcasters but spectrum has been reserved at 1.4 GHz for future DAB services. It is also expected that tests will be carried out after 2006 for a developing low frequency technology called DRM which will operate below 30 MHz. Additionally, a candidate DAB technology developed in the USA for digital simulcasting of existing analogue channels could eventually be implemented within AM and FM broadcast bands. Overall, the New Zealand radio industry seems somewhat skeptical and unwilling to commit to digital technology until it has proved its potential.

3.3. Television

3.3.1. Analogue Television

Existing services are expected to remain with little change until 2006. Beyond 2006, it is likely that the transfer from analogue to digital television will start in earnest. New Zealand has saturated UHF and VHF TV frequencies, which makes the in-band transition to digital television technically challenging. Additionally, overseas experience has shown that market penetration of digital receivers is slow and the situation in New Zealand is not expected to be any different. Despite this, it is expected that existing analogue services will cease when the penetration of digital receivers is sufficiently large.

3.3.2. Satellite Services

It is likely that there will continue to be a single major digital television provider (SKY Network Television Limited), and that satellite and cable will continue to be the major delivery mechanisms for the period 2001 to 2006.

Beyond this, satellite delivery of digital television is likely to continue, and could be augmented by additional ICT services, MDS and 12 GHz point to multi-point services offering better regional access, which may also provide competition in this sector.

3.3.3. Digital Terrestrial Services

During the period 2001 to 2006 Digital Terrestrial Television (DTT) is likely to emerge and some experimental transmissions have already taken place in New Zealand.

DTT is much lower in power and more robust than its analogue counterpart. It is expected that New Zealand will be able to introduce DTT in this way once a business case for its introduction can be justified.

The technology may have coverage problems and may require cooperation from the Crown to implement but it is likely that major cities will have DTT sometime between 2006 and 2011.

3.4. Synergistic Services

When services become digitised, broadcasting and telecommunications services can be provided within a single digital stream. It would appear that multi-service platforms will be an important delivery option and it has been predicted that broadcasting as an individual service may disappear entirely. [8]

There are two cases now where significant numbers of viewers around the world receive their TV programming through non-broadcasting channels. These are microwave point to multi point networks like MMDS, LMDS, narrow-casting, etc, and satellite delivery using direct to home reception in the fixed satellite service.

3.4.1. Fixed Point to Multi-Point Services (MDS)

It is not clear if MDS will be developed by 2006 but frequency in the 2.3 to 2.4 GHz range has already been auctioned for these services. Beyond 2006 LMDS will likely be available in major CBDs and some smaller cities.

3.4.2. Direct to Home Satellite Services

There is likely to be a significant increase of this type of service from 2001 to 2011 with one service already in the market and another in the planning stage.

3.5. Implications for this Project

As described throughout this section, a reasonable degree of technological change is expected in spectrum-related industries over the next ten to twenty years. While we have attempted to accommodate and embody these changes throughout this report, it is impossible to accurately predict their exact timing and impacts.

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[8] Future Spectrum Usage (2001), p 43.

The results presented in this report therefore need to be considered in this context. They represent our best estimate of the future value of spectrum licences in an environment that is subject to a high degree of complexity and even greater uncertainty.

4. The Renewal Process

This section outlines the general process that is being used to renew spectrum licences, the rationale underlying it, and the specific approach that has been adopted for deriving renewal fees.

4.1. Overview of Policy Decision

In June 2000, the Government released a public discussion document entitled *"Radiocommunications Act: Expiry of Management Rights and Spectrum Licences"*. This sought feedback from industry stakeholders on options for addressing the expiry of management rights and spectrum licences. The general consensus from respondents was that rights should be reallocated to existing right- and licence holders at least five years prior to expiry at a price to be negotiated with the Government. This five year lead time provides incumbents certainty in their operating environment and helps protect long-term investments in infrastructure and equipment.

After long and careful consideration of stakeholder responses and the impact of certain options on spectrum-dependent industries, the Government announced its policy decisions in May 2003. Those decisions were that:

- commercial spectrum rights be reallocated to existing right-holders five years before expiry for a further 20 years, subject to a review on a case by case basis to ensure consistency with New Zealand's international radio obligations and the general objective of maximising the value of the spectrum to society as a whole; and
- spectrum rights will be reallocated for a price to be determined by price-setting formulae that estimate the market value of the rights; and
- if existing right-holders do not wish to pay this price, the respective rights will be reallocated by way of auction.

4.2. Rationale

As noted above, Government's policy decision requires the derivation of a formula for setting renewal fees. Before we describe the general method used to estimate these renewal fees, it seems prudent to outline the apparent rationale underlying Government's policy decision.

Generally speaking, there are two ways that existing spectrum licences could be reallocated at (or prior to) expiry. First, they could be re-auctioned. Second, they could be offered to incumbents at a predetermined price. Government's policy decision essentially incorporates both methods, albeit in a cascading manner. But why not simply re-auction rights given that this process was used to allocate rights in the first place?

There are two main reasons why government might choose not to simply re-auction rights at (or prior to) expiry. First, it is economically and socially efficient to give incumbents first option on renewal of existing rights. In economic terms, the right of renewal provides greater certainty in the incumbent's operating environment, which encourages economically efficient levels of investment in the core infrastructure required to operate spectrum.[9] In social terms, the reallocation of spectrum to a new entrant will likely cause service discontinuity to consumers and impose significant switching costs to either continue the service with the incumbent at a different frequency, or migrate to a new service offering from the new right holder at the same frequency.

Second, spectrum rights are likely to be far more valuable to an incumbent right-holder than they are to a prospective new right-holder. This is because the incumbent has already invested in the expensive technology and associated infrastructure required to operate the spectrum, while a new entrant has not. To the extent that the incumbent's investment has been depreciated and earned its required rate of return, the new entrant has much higher future costs than the incumbent and, correspondingly, a much lower value attached to the spectrum rights.

Auctions are typically unable to extract from the incumbent this much higher marginal valuation because, by design, they result in the highest bidder (the incumbent) paying an amount roughly equal to the valuation placed on the item by the second highest bidder (a new entrant). Thus, auctions do not elicit a fair approximation of the true value placed on rights by an incumbent. This is less of an issue when rights are first allocated because there are no incumbents and hence each bidder faces roughly the same cost profile. In this case there is likely to be less variation in bidders' valuations, and the auction

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[9] If a new entrant plans to adopt more advanced technology than the incumbent, the reallocation of spectrum to the incumbent may be economically inefficient. However, we have no *prima facie* reason to believe that this would be the case.

price is therefore likely to be a more accurate reflection of the true value of spectrum to the highest bidder.

4.3. Candidate Approaches to Formula Design

Given government's policy mandate, the key task is to design a fair and transparent method for assessing renewal fees. Since the fee imposed should approximately reflect the expected market-value of rights, the first step is to identify variables that can reliably indicate this value. However, given the long and distant horizon over which expected value must be estimated, this is a difficult task. To further complicate matters, the evolution and uptake of new technologies, such as digital television and third generation cellular telephony, may fundamentally change spectrum use and therefore the future value of spectrum rights.

Notwithstanding these serious complications, a formula must be constructed that estimates a renewal fee for management rights and spectrum licences based on their expected future value. In its broadest terms, the value of rights over a given period equals the discounted expected net cash-flow (net present value or NPV) associated with its acquisition. The task of constructing a renewal fee formula then translates into prediction of NPV over a future period.

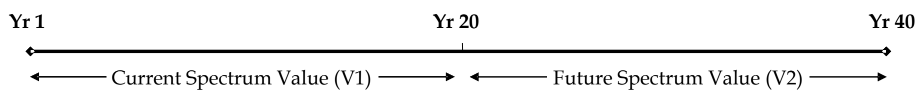
So how do we estimate the NPV associated with spectrum rights for an incumbent licence holder over a future 20-year period? There are two general candidate approaches. First, we could attempt to predict the likely net cash-flows for each year in the 20-year horizon and apply an appropriate discount rate to yield the NPV. Second, we could adopt a recursive approach, seeking to relate the future value of spectrum rights to their current value and to exploit this relationship to estimate the NPV.

In this context we have chosen to pursue the latter. Our reasons for doing so are threefold. First, we have market information on the value of spectrum rights, from the auction prices that incumbents paid to secure the existing right. Second, this approach is arguably more reliable than the alternative because it does not require predicting cash-flows for each year of the future 20-year horizon. Third, the formulae associated with this approach are readily updatable, so that refinement of the parameter values (and therefore the renewal fee) can occur as and when better information becomes available.

4.4. The Selected Approach to Formula Design

Although our chosen approach is likely to be more robust than the alternative, it is still conceptually challenging. To shed some light on our approach and elucidate the process, the diagram below illustrates the two values we are trying to relate. V1, which hereafter refers to the current value of spectrum, is assumed to equal the price that incumbents paid at auction. V2, which hereafter refers to the future value of spectrum, is the value that we want to relate to V1.

Current and Future Values of Spectrum Rights



To proceed with the analysis we first need to introduce some notation. Let:

- CF_i denote the net cash-flow for spectrum in Year *i*.
- r denote the discount rate used to derive net present values

Using this notation, the price that right-holders paid at auction to secure existing rights (*i.e.* V1) can be expressed as the expected NPV for years 1 to 20. This is given by:

$$V1 = \sum_{i=1}^{20} \frac{CF_i}{(1+r)^{i-1}} \qquad \text{Equation 1}$$

Similarly, the NPV of spectrum in the future period (when considered at the outset of that period) is given by:

$$V2 = \sum_{i=21}^{40} \frac{CF_i}{(1+r)^{i-21}} \qquad \text{Equation 2}$$

Now, if we assume that net cashflows grow by a constant proportion each year (say '*z*'), then V1 and V2 can readily be related to one another. To see how this is the case, consider the following. If net cashflow grows by some factor (*z*) each year, then net cashflow in any two consecutive years are related to one another by the formula:

$$CF_{i+1} = CF_i \times (1+z) \qquad \text{Equation 3}$$

Applying this formula recursively into the future, the net cashflow for the first year of the renewal period (CF_{21}) is related to net cashflow in the first year of the current period (CF_1) by the equation:

$$CF_{21} = CF_1 \times (1+z)^{20} \qquad \text{Equation 4}$$

Likewise, the net cashflow for the second year of the renewal period (CF_{22}) is related to the net cashflow in the second year of the current period (CF_2) by the equation:

$$CF_{22} = CF_2 \times (1+z)^{20} \qquad \text{Equation 5}$$

Extending this logic over a 20 year horizon, we obtain:

$$\begin{aligned} CF_{21} &= CF_1 \times (1+z)^{20} \\ CF_{22} &= CF_2 \times (1+z)^{20} \\ &\vdots \\ CF_{40} &= CF_{20} \times (1+z)^{20} \end{aligned} \qquad \text{Equation 6}$$

By substituting the formulae from Equation 6 into Equation 2 and rebasing the index (*i*) to cover the current period, we can rewrite V2 as:

$$\begin{aligned} \mathrm{V2} &= \sum_{i=21}^{40} \frac{CF_i}{(1+r)^{i-21}} \\ &= \sum_{i=1}^{20} \frac{CF_i \times (1+z)^{20}}{(1+r)^{i-1}} \\ &= (1+z)^{20} \times \sum_{i=1}^{20} \frac{CF_i}{(1+r)^{i-1}} \\ &= (1+z)^{20} \times V1 \end{aligned} \qquad \text{Equation 7}$$

Thus, Equation 7 shows that the future value of spectrum (V2) is directly related to the current value of spectrum (V1). In particular, V2 is equal to V1 multiplied 20 times by 1 plus the annual growth in net cashflow (z).

Finally, because V2 must be calculated and paid five years prior to the actual renewal of rights, it must be appropriately discounted. Thus, the final equation linking V1 and V2 is:

$$V2 = \frac{(1+z)^{20}}{(1+r)^{5}} \times V1 \qquad \text{Equation 8}$$

The key task then becomes estimating parameter values for *z* and *r* for each major use of spectrum, such as television, radio and cell phones. Since *r* is simply the discount rate used to yield net present values, a range of these can be used to infer a possible range of renewal fees for each spectrum licence. More discussion of the appropriate discount rate is provided in section 4.8. The estimation of *z* for each major spectrum use is more difficult.

The parameter *z* reflects past, current and future annual changes in net cashflow associated with spectrum use. The net cashflow received in any one year is equal to incoming cashflow (such as revenues) minus outgoing cash flow (such as operating expenses). That is,

$$CF_i = R_i - C_i$$

Now, if revenue (R_i) grows at some constant rate (say *a*) and costs (C_i) grow at some constant rate (say *b*) each year, the cashflow in the subsequent period will be:

$$CF_{i+1} = R_{i+1} - C_{i+1}$$

$$= (1+a) \times R_i - (1+b) \times C_i$$

$$= R_i - C_i + a \times R_i - b \times C_i$$

$$= CF_i + a \times R_i - b \times C_i \qquad \text{Equation 9}$$

Extending this logic to the next period yields:

$$CF_{i+2} = CF_{i+1} + a \times R_{i+1} - b \times C_{i+1}$$

$$= (CF_i + a \times R_i - b \times C_i) + a \times R_{i+1} - b \times C_{i+1}$$

$$= (CF_i + a \times R_i - b \times C_i) + a \times (1+a) \times R_i - b \times (1+b) \times C_i$$

$$= CF_i + a \times (2+a) \times R_i - b \times (2+b) \times C_i$$

Thus, net cashflow quickly becomes a complex and nonlinear function of the initial period cashflow (CF_i) as well as the initial values for R_i and C_i and also their corresponding growth rates (a and b, respectively). Furthermore, even if CF_i was known and a and b could be estimated, the result depends crucially on the composition of R_i and C_i in CF_i. An added concern is that, dependent on the values ascribed to a and b, this approach can also lead to profit margins that are steadily increasing or decreasing over time.

To make the formula more amenable to implementation over the long time horizons with which this report is concerned, we have assumed that the growth rates for revenues and costs are roughly equal. This assumption also ensures that profit margins on revenues are not steadily increasing or decreasing over time. Rather, this assumption ensures that profit margins on revenues are constant over time, which we believe is broadly correct.[10] One justification for this is that in a competitive industry such as those under consideration, entry and exit will tend to equalise return on capital over time. Assuming that the amount of capital required to generate a dollar of revenue remains constant over time means that constant returns on capital will translate into constant returns on revenue.

Having made this assumption, Equation 9 becomes:

$$\begin{aligned} CF_{i+1} &= CF_i + a \times R_i - b \times C_i \\ &= CF_i + a \times R_i - a \times C_i \\ &= (1+a) \times CF_i \end{aligned} \qquad \text{Equation 10}$$

Now, Equation 10 depends only on initial cashflow (CF_i) and the growth rate of revenue (a). Of course, we could equally have simplified the equation to be based on cost growth (b). However, during the completion of this report we found that it was easier to construct accurate and reliable forecasts of future revenue streams than it was to construct accurate and reliable forecasts of future cost streams. We therefore chose to define Equation 10 in terms of revenue growth, rather than cost growth.

Comparing Equation 10 to Equation 3, z is now defined simply as forecast average annual revenue growth. So, to implement the pricing formula in Equation 8, our main task now is to estimate the future growth rate of

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[10] See Appendix 4 for a demonstration of the equivalence of these two assumptions.

revenue. This requires us to decide what the relevant revenues are for each major use of spectrum, which is covered in subsequent sections of this document.

4.5. Adjustments to the Baseline Formula

4.5.1. Existing licences or renewal periods other than 20 years

Equation 8 provides a fairly simple method for calculating the fees for renewing existing 20-year spectrum licences (or management rights) for a further 20 years. However, some existing spectrum licences were issued for periods longer or shorter than 20 years. Similarly, the renewal term for some spectrum licences may be longer or shorter than 20 years. Accordingly, the formula in Equation 8 needs to accommodate these exceptions.

In general, the pricing formula to renew an existing *n*-year licence for a further *m*-years (where the renewal fee is paid 5 years in advance) is given by:

$$V_2 = \frac{(1+z)^n}{(1+r)^5} \times V_1 \times \left(\frac{1 - \left({(1+z)}/{(1+r)} \right)^m}{1 - \left({(1+z)}/{(1+r)} \right)^n} \right) \qquad \text{Equation 11}$$

The derivation of this formula is demonstrated in Appendix 5. Note that, when $n = m = 20$ (as is the case when a 20-year licence is renewed for a further 20 years), Equation 11 simplifies to Equation 8.

In the unlikely event that the value of z is exactly equal to the value of r, the calculation required in Equation 11 is not possible (the last term becomes 0/0 which is indeterminate). This can be avoided by simply changing z or r by a very small amount.

4.5.2. Annual payments

In the preceding sections we derived equations (Equation 8 or 11) linking the lump-sum fee for licence renewal (V2) to the price that was initially paid (V1). We have been asked to also provide for the possibility that right-holders want to make a sequence of annual payments instead of a single lump-sum fee. This section translates the lump-sum fee into an amount to be paid in each year of the renewal period.

First, note that V2 is based on payment five years prior to expiry. Since annual payment will occur during the renewal period, we must first adjust for this basic timing difference. If we denote $V2_{outset}$ to represent a lump sum paid at the outset of the renewal period instead of 5 years earlier, this is equal to:

$$V2_{\text{outset}} = (1+r)^5 \times V2 \qquad \text{Equation 12}$$

We then wish to convert $V2_{outset}$ to a series of n constant annual payments, such that the present value of these payments is equal to $V2_{outset}$. Using A2 to denote an annual payment (for one year), we thus require that:

$$\sum_{i=1}^{n} \frac{A2}{(1+r)^{i-1}} = V2_{\text{outset}} \qquad \text{Equation 13}$$

We can express this in terms of V2 as:

$$\sum_{i=1}^{n} \frac{A2}{(1+r)^{i-1}} = (1+r)^5 \times V2 \qquad \text{Equation 14}$$

Since A2 is constant, we have:

$$A2 = \frac{(1+r)^5 \times V2}{\sum_{i=1}^{n} \frac{1}{(1+r)^{i-1}}} \qquad \text{Equation 15}$$

Equation 15 presents the final formula for deriving annual payments based on the lump sum payment (V2) in Equation 8 or Equation 11.

4.6. Adjustments to Base and Renewal Prices

As can be seen above, the renewal prices depend heavily on the original base prices. Analysis of the auction prices reveals that technically identical licenses sometimes sold for very different prices. For example, Table 2 shows the auction prices for seven UHF-TV licenses in Christchurch. All of these licenses are technically identical in that the transmitters are at the same location (Sugarloaf) and are for the same power. In light of this observation, one approach would be to consider using some form of “normalisation” or averaging to adjust the prices paid at auction for spectrum licenses, prior to applying our formula to calculate their value at expiry.

One point worth making at the outset is that a range of prices for identical licenses, such as that shown in Table 2, is exactly the kind of outcome that we would expect from an efficient allocation mechanism when there is a relatively thin market and when there is heterogeneity in buyers' willingness to pay. In our view, heterogeneity in selling prices should not be regarded as a bad outcome *per se*.

In this subsection we discuss the issues surrounding such adjustments. In considering these issues, it is important to keep in mind the stated objectives of the government's policy on the reallocation of spectrum rights at expiry. In particular, the renewal prices must meet "the general objective of maximising the value of spectrum to society as a whole" and the prices must ensure that the Crown receives "a fair financial return for the use of spectrum".[11] We consider two different methodologies to make adjustments to prices. The first involves averaging of base prices and the second involves introducing 'reserve' prices into the pricing formula. In the context of our framework, the first approach adjusts V1 while the second approach adjusts V2. In either case, however, the objective is the same: to change the distribution of the V2 values.

Table 2 Christchurch UHF-TV License Auction Prices.

Channel	Winning Bidder	Amount Paid
CH 44	Joanna McMenamin	$47,000
CH 60	Sophomore Holdings Ltd	$21,124
CH 52	Christchurch Polytechnic	$1,000
CH 28	Sky Network Television Ltd	$201
CH 32	Sky Network Television Ltd	$201
CH 48	Broadcast Communications Ltd	$201
CH 56	Shureview Radio & Television Services	$1

4.6.1. Averaging of Base Prices

Since the spectrum licenses within a given category of license (such as radio or TV) have different characteristics in terms of location and power, some basis needs to be used to implement the averaging. The most attractive option is to use data on the population covered by each license to calculate a *per-capita* price, and then average these prices. The advantages and disadvantages presented in Table 3 assume that per-capita averaging is used, though the arguments will be the same for any other basis.

[11] Executive Summary, *Radio Spectrum: Rights at Expiry*, Cabinet Paper, 12 May 2003.

Whether or not base prices should be averaged requires careful consideration of the advantages and disadvantages outlined in Table 3. However, by agreement with MED, this decision lies beyond the scope of this report.

Table 3 Advantages and Disadvantages of Averaging Base Prices.

Advantages	Disadvantages
❖ Potentially more equitable: A level playing-field is created whereby similar assets have similar values.	❖ Potentially less equitable: A cost advantage may be conferred on spectrum users who are more profitable and have a higher willingness to pay for spectrum.
❖ *Unweighted* averaging of per-capita prices may increase total revenue, but only if original prices for licenses that covered larger populations were relatively low (see Appendix 3).	❖ *Weighted* averaging of per-capita prices using non-arbitrary weights will not increase total revenue (see Appendix 3).
	❖ Potentially reduces welfare: It is likely that the averaged prices will be above the willingness to pay of some spectrum users, and so the renewal prices will not meet the main objective of the government's policy.
	❖ Imposes arbitrary distortions on original market signals.
	❖ Potentially creates distortions in the secondary market for spectrum.
	❖ May set a precedent for future spectrum auctions and may distort bidder behaviour in these auctions.

4.6.2. Introducing 'Reserve' Prices

An alternative methodology to averaging of base prices is to introduce 'reserve' prices into the renewal pricing formula. In this case, if the reserve price for a given license is *R*, the adjusted renewal fee becomes:

$$V2_{Adjusted} = \max[V2, R]$$

Thus, all renewal prices that fall below *R* will be adjusted upwards to *R*, while all other (higher) renewal prices remain unchanged.

Introducing relatively low reserve prices is preferable to averaging because as long as the reserve price is not too high, it means that fewer prices are likely to be adjusted, and hence there is less possibility of creating welfare losses and market distortions. Also, this method creates unidirectional changes to V2 (renewal prices can only increase), while averaging causes both increases and decreases to occur.

The key difficulty with implementing reserve prices is determining the appropriate value of *R*. One consideration is the level of any reserve price that will apply to the auction of a license in the event that the existing right-holder chooses not to renew for the fixed price. The renewal reserve price should not be set at a level greater than the reserve price that would be set in such an auction. A further general consideration is that to avoid imposing many distortions on the spectrum market, the reserve price should be set reasonably low, so that it applies to a relatively small subset of spectrum rights.

One possibility is to set the renewal reserve price (*R*) equal to the cost of running an auction for the spectrum right. It should be noted, however, that there may be some justification for setting the reserve price even lower than this. The reason is that spectrum right-holders will presumably provide services that generate a stream of welfare benefits over time into the future. In determining the reserve price, this should be traded off against the cost of running the auction.

4.7. Interpretation of Base Prices

A further issue to consider is that some rights were granted under the incumbency provisions of the Act, rather than being sold. There are some such rights in all of the three main categories of radio, television, and cellular. These rights were sold to incumbents for prices that were a function of gross revenue and were determined through commercial negotiations. In such cases, there is an issue of determining the appropriate base price (the value V1) to be used in our formulae. There are two possibilities which we discuss here.

The first possibility is to take the view that since the original incumbency prices were negotiated and willingly accepted by incumbents, they should be reasonable approximations to market prices. In this case, the value of V1 would be the original price at which the license was sold to the incumbent.

Alternatively, we could use the fact that in most cases, additional information about the market value of these licenses has subsequently been revealed through the auctioning of similar licenses. Accordingly, the value of V1 for incumbency licenses could be established by taking population-based averages of the prices of similar licenses that have subsequently sold.

There are no obvious criteria for choosing between these two alternatives, but we tend towards the use of population-based averages provided there is a sufficient number of competitively priced and similar licenses from which to calculate the average.

4.8. The Appropriate Discount Rate

In addition to depending on the base prices, the results produced by the pricing formulae are highly sensitive to the discount rate (*r*), which appears in the denominator of each equation. The discount rate is a proxy for the weighted average cost of capital (WACC), which in reality differs across time and across industries. A search of the New Zealand literature revealed that a WACC of between 11% and 12% is appropriate for spectrum licences for television, radio and cellular telephony. [12]

Our literature search did not identify an appropriate WACC for MDS because we were unable to find WACC data for any firm specialising in MDS. In the absence of such data, and recognising that there is a narrow spread of WACC across radio, TV and cellular telephony, and that MDS has uses that are not obviously different from this set of industries, we recommend that the same range apply to MDS.

[12] See for instance http://www.inl.co.nz/news/archive/8027.pdf or http://www.comcom.govt.nz/telecommunications/obligations/PWCCostofCapital(4).PDF

5. Radio and Television Spectrum Licences

Since radio and television both use spectrum for broadcasting services and because the economic factors affecting both industries are broadly similar, we have grouped them together in this section.

5.1. Evolution of the Industries

This section provides some context to the current state of the television and radio sectors by briefly outlining their evolution to date. For ease of reading, these evolutions are presented in chronological order.[13]

5.1.1. Evolution of the Television industry in New Zealand

1950s Experimental television broadcasts begin
1960 The first monochrome TV broadcast commences (TV1) and later that year the broadcasting fee is introduced
1961 Television advertising is introduced
1962 New Zealand Broadcasting Corporation is created
1969 Dougal Stevenson presents first news broadcast
1973 Colour TV broadcasts begin
1975 New Zealand Broadcasting Commission is dissolved and replaced by TV1, TV2 and Radio New Zealand
1975 TV2 commences broadcasts
1981 First solid state medium power television transmitter commissioned.
1984 Teletext is introduced
1988 The Broadcasting Corporation of New Zealand was replaced with two state-owned enterprises, Radio New Zealand Limited (RNZ) and Television New Zealand Limited (TVNZ).
1988 TVNZ was required to vest its transmission assets in a subsidiary company, Broadcast Communications Limited (BCL).
1989 TV3 started
1989 The Broadcasting Act established NZ On Air and the Broadcasting Standards Authority
1990 Sky Television started
1994 TV2 moves to 24 hour transmission
1997 TV4 is launched
1998 Prime started

[13] Information in this timeline was sourced from the BCL and TVNZ websites and the New Zealand Official Yearbook 2002.

1998 First non-commercial station (Triangle TV) begins
2000 The broadcasting fee is abolished
2001 TV1 and TV2 are simulcast via satellite
2003 TVNZ adopts its new charter

5.1.2. Evolution of the Radio industry in New Zealand

1921 Professor Jack transmits the first radio programme in New Zealand, from Dunedin
1923 Broadcasting regulations introduced under Post & Telegraph Act 1920
1923 Public Broadcasting Fee introduced
1925 The Radio Broadcasting Company of New Zealand Ltd (RBC) was established.
1932 A Government Bill creates the New Zealand Broadcasting Board (NZBB), which purchases the RBC.
1935 The government-owned National Commercial Broadcasting Service (NCBS) begins, with the acquisition of 1ZB.
1936 New Zealand Government assumed control of public broadcasting. The NZBB was dismantled and the National Broadcasting Service (NBS) was established as a separate government department.
1936 New Zealand is first country in the world to broadcast Parliament live
1943 The NCBS and NBS amalgamate to become the National Broadcasting Service (NBS).
1946 The NBS is renamed the New Zealand Broadcasting Service (NZBS) – a government department.
1948 The short-wave service begins transmission on Dominion Day. It is called Radio New Zealand.
1962 NZBS replaced by New Zealand Broadcasting Corporation (NZBC)
1964 The national programme network begins
1965 The idea for Radio Hauraki is crystallized. David Gapes moves to Auckland to start the station.
1975 The NZBC is restructured into Radio New Zealand and two television channels, under the Broadcasting Corporation of New Zealand (BCNZ). The YC stations are renamed the 'Concert Programme'.
1982 The first FM transmissions in stereo are broadcast during a week-long trial in Wellington
1988 BCNZ dissolved by Broadcasting Corporation of New Zealand Restructuring Act 1988, replaced by Radio New Zealand (RNZ) and Television New Zealand (TVNZ)

1989 Broadcasting Act 1989 establishes Broadcasting Commission, an independent body operating under the name New Zealand On Air

1995 The Radio New Zealand Act 1995 is passed, establishing Radio NZ as a stand-alone Crown entity

1996 The commercial operations of RNZ are sold to New Zealand Radio Network Limited's consortium

1998 RNZ begins radio production using digital audio.

1999 RNZ News begins using digital audio.

2000 National Radio and Concert FM begin to be carried on the Sky Digital satellite system. National Radio begins transmission on FM in Auckland and Taupo.

2000 The broadcasting fee is abolished

5.2. Current State of the Industries

5.2.1. Television Industry

Since the first broadcast in 1960, New Zealand television has grown rapidly to become quite competitive. By the end of 2002, there were five free-to-air national stations (TV1, TV2, TV3, TV4 and Prime) and an additional 40+ national pay-tv channels, all of which are operated by Sky.

New Zealand also has a number of regional television stations, each of which has its own particular programming focus and target demographic audience.

5.2.2. Radio Industry

Since the broadcasting reforms of the late 1980s, the number of registered radio frequencies has increased significantly. In July 1988, there were 47 AM and 17 FM stations. By November 2001, there were 170 AM and 528 FM licences to broadcast, 70% of which were privately owned.

5.3. Estimating *z*

In order to estimate renewal fees for radio and television licences we need to obtain estimates of z, a proxy for annual growth in net cashflow that allows us to relate the future value of spectrum licences to the price paid for existing ones. As shown in section 4.4, the value of this depends on estimates of annual revenue growth (maintaining our assumption that revenues and costs grow at the same rate), which in turn requires identification of the relevant revenues. In this section we identify the relevant revenues to estimate annual growth rates out to 2030, the date at which renewed radio and television licences will lapse. We then use these to infer the values of z and, ultimately, the level of renewal fees.

5.3.1. Estimating Revenue Growth

Although radio and television stations may receive some revenue from peripheral activities, their most significant revenue stream is advertising.[14] For instance, advertising comprised 86% of TVNZ's operating revenue (excluding transmission services revenue) in 2002 and a similar proportion in 2001.

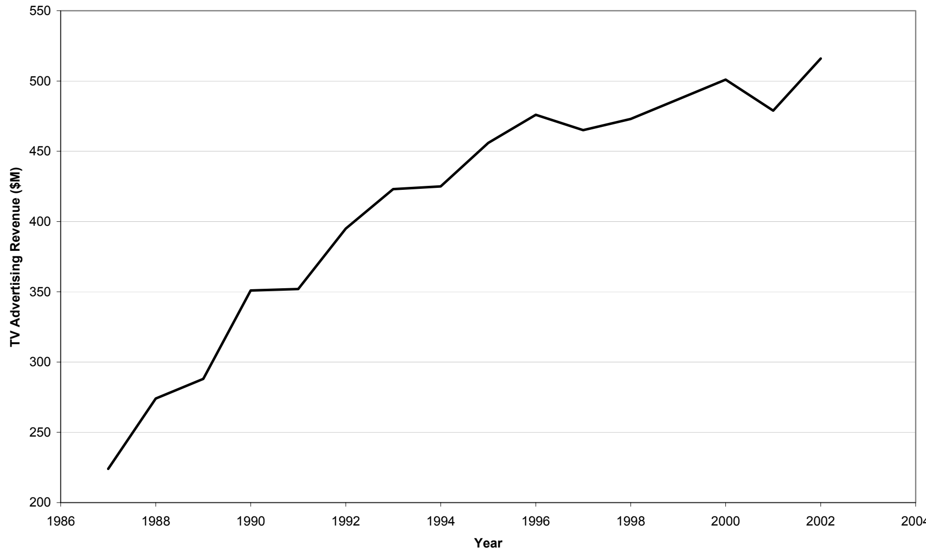
The significance of these income streams is also illustrated in the graphs below, which show the total value of New Zealand television (radio) advertising from 1987 to 2002. In 1987, advertising was worth $224 m to the television industry and $100 m to the radio industry. By 2002 advertising revenue had grown to $572 m for television and $203 m for radio, representing annual average growth rates of 5.72% and 3.33%, respectively.

It seems likely that an important reason that radio advertising had a slower growth rate than television advertising is because the former lost market share to the latter. Radio's share of total media advertising revenue was 14% in 1987 and 13% in 2002, while television's share was 31% in 1987 and 33% in 2002.

While advertising revenue has grown rapidly in both industries over the last fifteen years, we must acknowledge that these trends may not persist in future. Indeed, even within the last fifteen years there have been sub-periods where annual growth rates are markedly different. For example, the annual rate of growth for television between 1987 and 1992 was over 12%, while between 1997 and 2002 it was only 2.1%. Hence growth rates are not stable over time and, in order to project a future revenue growth rate upon which to base z, we need a reliable method for predicting future radio and television advertising revenues.

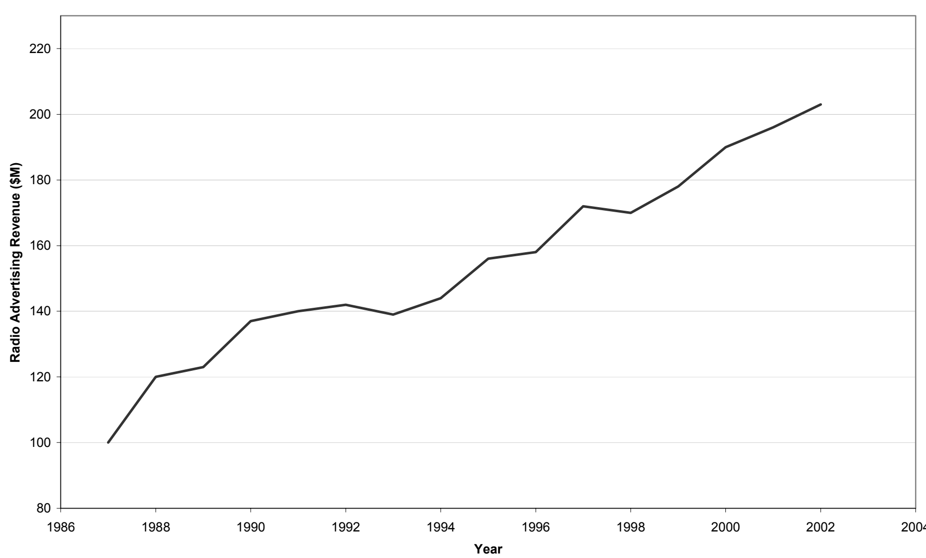
[14] We acknowledge that subscription fees are a significant additional income stream for pay-tv but explicitly exclude them from the discussion as they apply to only one organization at present, Sky Television Limited. Furthermore, we do not have sufficient information on past (and likely future) uptake of pay-tv subscriptions upon which to base a rigorous and defensible analysis. Finally, Sky Television's digital service does not use the same spectrum that we are discussing in this section of the report.

Figure 1 Annual Television Advertising Revenue ($M)



Source: Communication Agencies Association of New Zealand (CAANZ)

Figure 2 Annual Radio Advertising Revenue ($M).

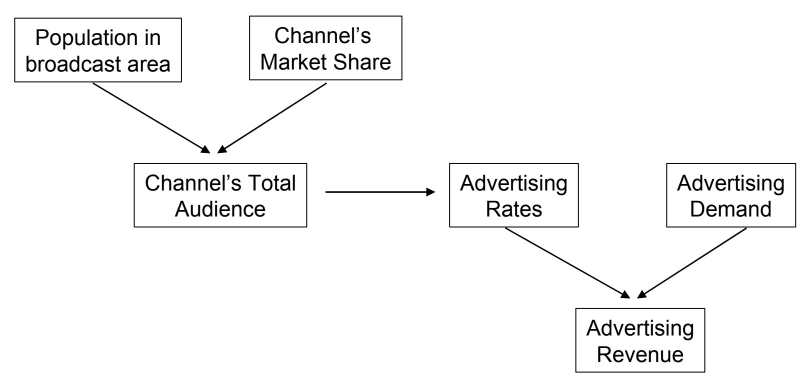


Source: CAANZ

The main task at this stage is to identify a variable or set of variables (*i.e.* drivers) that can accurately predict future television and radio advertising revenues. Once these are identified, we then use forecasts of these drivers to yield forecasts of advertising revenues. These latter forecasts are then used to calculate implied annual growth rates upon which to base *z*.

All other things being equal, the most reliable predictor of future advertising revenues is probably population. The reason for this is quite straightforward. As the population in a broadcast area grows, the number of viewers (listeners) grows in the same proportion (assuming that audience share is roughly static). As audience grows, the station can charge higher advertising rates. As advertising rates increase, so too does advertising revenue.[15] Thus, population and advertising revenue are closely correlated. This relationship is illustrated in the figure below.

Relationship between Population and Advertising Revenue



To verify this seemingly strong relationship, we ran two simple linear (OLS) regressions. One regressed national television advertising revenue on population, while the other regressed national radio advertising revenue on population. Both sets of results confirm our hypothesis. The television regression had an R^2 of 88% and the estimated coefficient on population was significant at the 1% level. The radio regression had an R^2 of 93% and the estimated coefficient on population was also significant at the 1% level.

However, before these regressions can be used to validly imply future advertising growth rates, we need to ensure that they are not 'spurious'.

[15] This latter relationship is particularly strong since the quantity of advertising does not change much over time (*i.e.* stations tend to allocate the same amount of broadcast time to advertisements each year).

Spurious regressions can result when two or more time series variables, all of which are non-stationary, are regressed on one another. Such regressions have the outward appearance of a good model (*i.e.* high R^2 and significant regressors), but the regression variables themselves are not causally related.

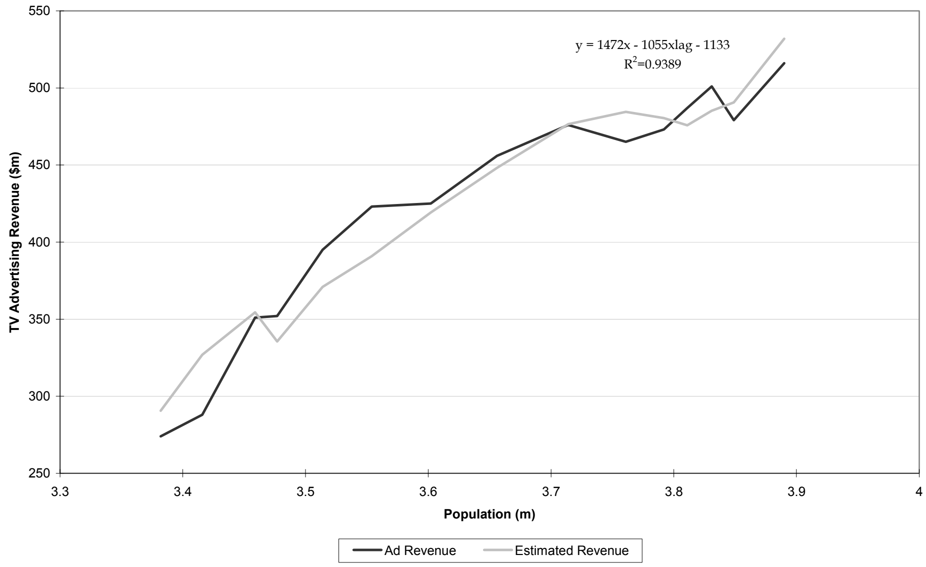
Because of the risk of spurious regressions, econometricians commonly transform the variables first to ensure stationarity. Regressions are then run on the transformed variables, with the risk of spuriousness eliminated. The usual method for transforming the variables is to difference them, which involves expressing each variable as the change from one period to the next. Unfortunately, regressions using differenced variables can lose information about the long-term relationship between the (non-differenced) variables, which is what we are ultimately trying to model. Differencing is therefore not always a satisfactory solution.

Fortunately, there is a case where non-stationary variables *can* be regressed on one another without having to transform them first. This occurs when there is some linear combination of the variables that is stationary, despite non-stationarity of the variables in their own right. When this can be done, we say that the variables are *cointegrated*. Thus, one way to determine whether spuriousness is a problem for our two estimated regressions, given that the variables are non-stationary, is to test for cointegration.

Returning now to our estimated regressions, we found that the radio advertising revenue regression was cointegrated but the television advertising revenue regression was not. Consequently, only the radio regression can be used for forecasting purposes. To solve the spurious regression problem for the television regression we tried running it again on differenced variables. Unfortunately, the explanatory power of the model was very low. Next, we tried adding a lagged population term. This solved the spurious regression problem and improved explanatory power. This latter regression was therefore used to generate forecasts of future television advertising revenue. [16] The fitted regression lines and actual data points are plotted in Figure 3 and Figure 4.

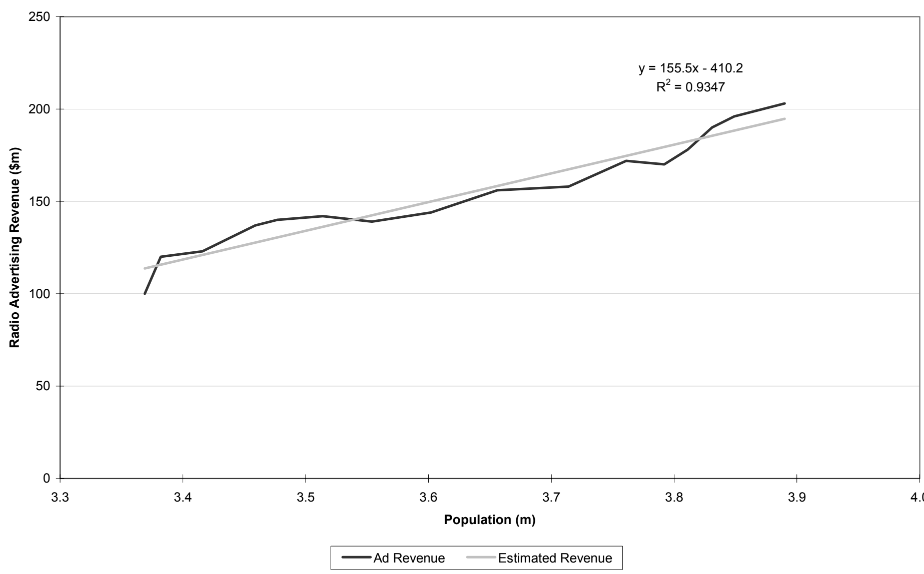
[16] A number of other regressors (such as GDP per capita) were included in the initial model specification. However, these were all insignificant and subsequently omitted.

Figure 3 Final Population – Television Advertising Revenue Regression



Sources: CAANZ and Covec

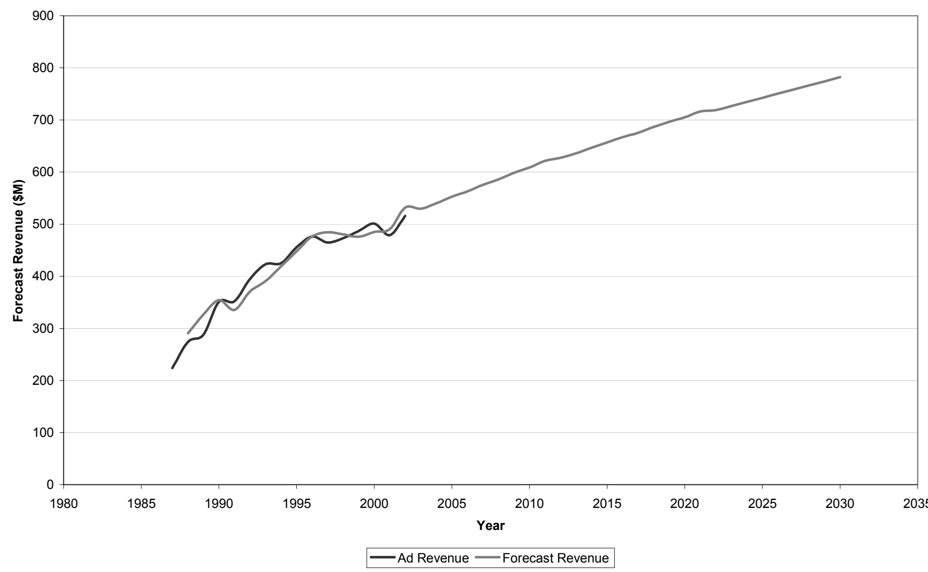
Figure 4 Final Population – Radio Advertising Revenue Regression



Sources: CAANZ and Covec

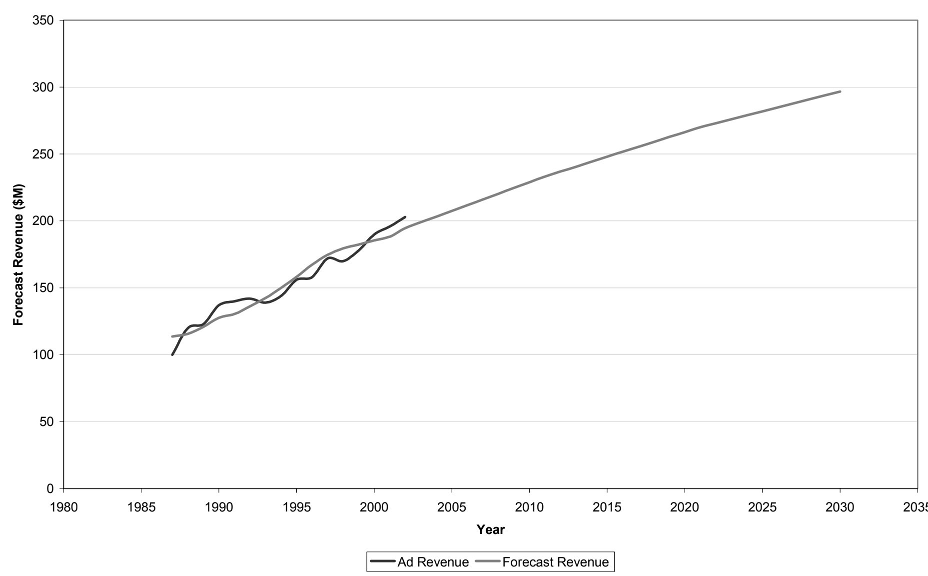
Now that we have identified an accurate 'driver', we need to obtain forecasts of this driver to generate revenue forecasts. Statistics New Zealand provides low, medium and high national forecasts out to 2031. Based on their medium population projections and the regressions above, we have forecast television and radio advertising revenues to 2030, as shown in Figure 5 and Figure 6.

Figure 5 Forecast TV Advertising Revenue to 2030



Source: CAANZ, Statistics New Zealand & Covec

Figure 6 Forecast Radio Advertising Revenue to 2030



Source: CAANZ, Statistics New Zealand & Covec

According to these forecasts, television advertising revenue is expected to reach $782 m by 2030 and radio advertising is expected to reach $296 m. These forecasts represent average growth rates between 1990 (the start of the current licence period) and 2030 of 2.02% and 1.95%, respectively. These are the revenue growth figures that will be used for the value of *z*.

5.3.2. Deriving the final formula

In the previous subsection we identified national-level revenue growth estimates upon which to calculate the values of *z*. But, since revenue growth is driven by population growth, which itself varies noticeably by region, we need to adjust the values of *z* to take account of population growth in the broadcast area. We therefore suggest adjusting the formula in Equation 8 to become:

$$\mathrm{V2} = \frac{\left[1 + \text{revenue growth} \times \left(\frac{\text{regional population growth}}{\text{national population growth}}\right)\right]^{20}}{(1+r)^5} \times V1$$

Substituting the values derived in the previous section, and based on Statistics New Zealand's medium national population growth projections, the equation for television spectrum licenses becomes:

$$V2 = \frac{\left[1 + 2.02\% \times \left(\frac{\text{regional population growth}}{0.75\%}\right)\right]^{20}}{(1+r)^5} \times V1 \qquad \text{Equation 16}$$

Similarly, the corresponding equation for radio becomes:

$$V2 = \frac{\left[1 + 1.95\% \times \left(\frac{\text{regional population growth}}{0.75\%}\right)\right]^{20}}{(1+r)^5} \times V1 \qquad \text{Equation 17}$$

where regional population growth denotes expected annual population growth in the broadcast region between 2001 and 2021.[17]

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[17] While the future license periods extend to 2030, regional estimates of population growth are only available to 2021. We therefore use the growth rate between 2001 and 2021 to infer likely population growth out to 2030.

5.4. Implementing the Formula

To implement the adjusted formula for a given television or radio spectrum licence, we simply need to follow these steps:

- ❖ Identify the region(s) that the licence covers.
- ❖ Use appendices 1 and 2 to obtain estimates of population growth for the area(s) that best match the region covered by the licence.
- ❖ For television licences, substitute the regional population growth estimate (from the appendix) into Equation 16. For radio, substitute the growth estimate into Equation 17.
- ❖ Decide on an appropriate discount rate.
- ❖ Calculate the result.
- ❖ If the renewal period or the license period is not equal to 20 years, use Equation 11 to adjust the renewal fee to account for this.
- ❖ If payments are to be made annually rather than lump sum, use Equation 15 to calculate the annual payments for each year of the renewal period.

By way of example, suppose we wanted to assess the renewal fee for a television licence covering Auckland, where population growth between 2001 and 2021 is estimated at 1.54%. Suppose that the licence sold for $100,000 at the last auction and the appropriate discount rate is 11%. The renewal fee would be calculated as:

$$V2 = \frac{\left[1 + 2.02\% \times \left(\frac{1.54\%}{0.75\%}\right)\right]^{20}}{(1+0.11)^{5}} \times V1$$

$$= 1.3378 \times V1$$

$$= \$133,777$$

Hence the licence renewal fee will be $133,777, 34% higher than the price paid for the existing licence. Note that this result is highly influenced by the presence of a discount factor in the denominator to reflect renewal fees being levied 5 years prior to the commencement of the licence period. If these fees were calculated at the outset of that period, rather than 5 years prior, the renewal fee in this instance would be $225,422, 125% higher than the price paid for the existing licence.

Similarly for radio, suppose we wanted to assess the renewal fee for a radio licence covering Wellington, where population growth between 2001 and 2021 is estimated at 0.32%. Suppose that the licence sold for $25,000 at the last auction and the appropriate discount rate is 11%. The renewal fee would be calculated as:

$$V2 = \frac{\left[1 + 1.95\% \times \left(\frac{0.32\%}{0.75\%}\right)\right]^{20}}{(1+0.11)^{5}} \times V1$$

$$= 0.7004 \times V1$$

$$= \$17{,}510$$

Hence the licence renewal fee will be $17,510, 30% lower than the price paid for the existing licence. Once again, this reduction is largely due to renewal fees being levied 5 years prior to the commencement of the licence period. If these fees were calculated at the outset of that period, rather than 5 years prior, the renewal fee in this instance would be $29,506, 18% higher than the price paid for the existing licence.

6. Cellular Spectrum Licenses

6.1. Evolution of the Cellular Phone Industry

This section provides some context to the current state of the cellular telephony sector by briefly outlining its evolution to date. For ease of reading, this evolution is presented in chronological order.[18]

1982 Paging services are introduced.

1987 Telecom acquires telecommunications services from NZ Post and becomes a SOE. Telecom introduces analogue mobile services, using AMPS.

1989 The telecommunications market is deregulated

1993 BellSouth enters the market using GSM digital technology.

1993 Telecom supplements its AMPS technology with D-AMPS.

1998 Vodafone buys BellSouth's network in November and enters the mobile market. At this time 17% of New Zealanders own a mobile phone.

2000 Telecom has 1,000,000 mobile customer connections. Around 49.5% of New Zealanders own a mobile phone.

2000 Vodafone introduces WAP (Wireless Application Protocol).

2001 Telecom introduces its CDMA wireless network, covering more than 98% of the population. Vodafone has more than 1,000,000 customers with the network covering more than 97% of population. Vodafone and Telecom networks are made compatible for text messaging.

2002 Telecom partners with Alcatel to manage the development and integration of its Trans-Tasman Next Generation Network (NGN). Telecom signs up 200,000 more customers on its 027 CDMA network 14 months after its launching. Vodafone launches PXT picture messaging.

6.2. Current State of Cellular Telecommunications Industry

At the present time, mobile telecommunications services in New Zealand are operated using first and second-generation technologies (1G, 2G and 2.5G) and the market is a duopoly comprising Telecom and Vodafone. Telecom is operating with both AMPS/D-AMPS and CDMA technologies through its 025

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[18] Information in this timeline was sourced from www.telecom.co.nz, www.vodafone.co.nz, Commerce Commission Decision No. 479, and *New Zealand Telecommunications 1987 - 2000*, Ministry of Commerce, February 2000.

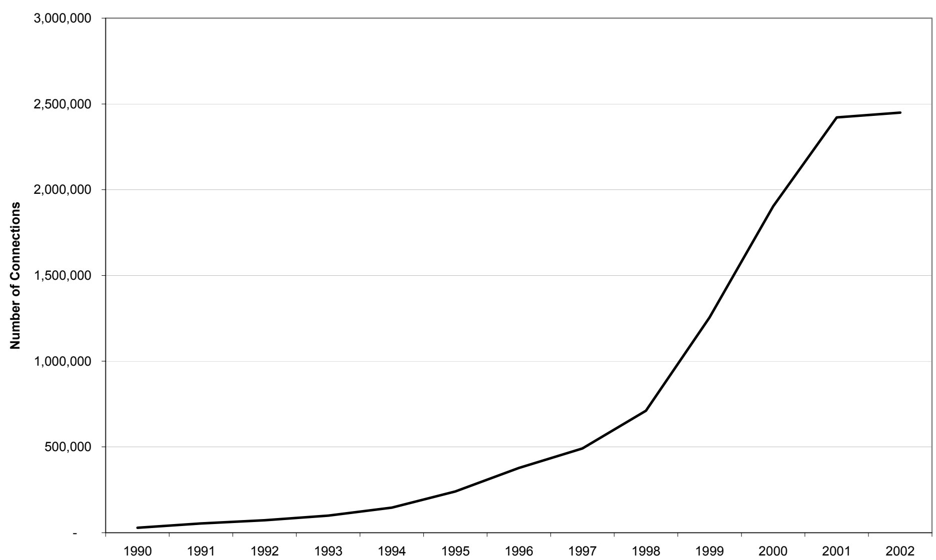
and 027 prefixes. Vodafone is operating its 021 prefix using both the GSM system (a 2G technology) and the GPRS system (a 2.5G technology). Vodafone also resells their mobile offerings to TelstraClear who operates using the 029 prefix.

The services provided by these operators at present include:

- National and international calls
- Text messaging, broadcast text, message alerts, and picture messaging
- Caller identification and call diversion
- Internet services e.g. WAP and email
- International roaming
- Data transmission and fax sending
- Topping-up accounts via ATMs
- Mobile commerce applications such as Vodafone's m-ticket

With steady increases in the number of mobiles services available and gradually falling prices, the number of consumers connecting to a cellular service has been increasing rapidly over time. Figure 7 shows the number of connections as at the end of each year for 1990 to 2002. By December 2002, around 2.5 million New Zealanders had a connection.

Figure 7 Number of Cellphone Connections in New Zealand.



Sources: Commerce Commission and www.vodafone.co.nz.

6.3. Modelling the Value of Cellular Spectrum

As for the radio and television industries, the goal of this section is to find a relationship between the value of current cellular spectrum rights and the value of renewing such rights. However, obtaining accurate estimates of the future value of cellular spectrum is more complicated because, unlike radio and television, the cellular industry is not yet mature. As shown in Figure 7, the number of subscribers to cellular networks experienced dramatic growth rates between around 1995 and 2001. More recently, there has been a fall-off in the growth of new connections, indicating that this aspect of the market is approaching its saturation point.

Valuing cellular spectrum is also complicated by data limitations. In the previous section, forecasts of future radio and television industry revenues could be generated using models that were estimated from historical data series of industry revenues. For the New Zealand cellular industry, reliable data on total industry revenues are only available for the period from 1999 to 2003, i.e., 5 data points. Given that forecasts of revenues need to be generated out to 2031, the accuracy of such forecasts will be adversely affected by the lack of available historical data.

A final complication is the presence of technological change in the cellular industry. As has been mentioned previously, new technologies are emerging which may use different spectrum frequency ranges than those covered by existing cellular spectrum rights. The adoption of such technologies is therefore likely to have a significant impact on the value of spectrum rights associated with existing technologies.

With these limitations in mind, in the following two subsections we discuss two alternative approaches to valuing cellular spectrum rights at expiry. Both approaches are based on a discounted cashflow analysis, but differ in the way that the inputs to such an analysis are generated. In particular, the first approach is the same as what we have used for the radio and television industries, while the second approach involves conducting a more detailed valuation exercise.

6.4. Approach 1: Formulaic Valuation

The first possible approach to valuing cellular spectrum rights at expiry is to follow the same methodology as was used for the radio and television industries. As for those industries, this requires generating estimates of the model variable z, which is the modelled (constant) growth rate of industry net cashflows. As before, we maintain the assumption that revenues and costs grow at the same rate, and hence only estimate the growth rate of revenue.

In this subsection we discuss the issues relating to implementing such an approach for cellular spectrum rights. The steps to be followed are somewhat simpler than that for radio and television, because all cellular rights have nationwide coverage, so we do not need to consider regional effects.

6.4.1. Estimating *z*

The first step in the process is to generate an estimated value of z that will apply for the period that the renewed right covers. Historical data on cellular industry revenues are needed to form projections of future revenues and hence estimate the appropriate value of z. The New Zealand cellular market is dominated by Telecom and Vodafone, hence for the purposes of this report we define cellular industry revenues to be the sum of the revenues related to cellular services for these two firms.[19]

We have collated the relevant revenues for both firms from annual reports and press releases. This data is shown in Table 4. Given that the available data series consists of only five data points, it is not possible to use a very rich econometric model to forecast future revenues. However, we have found that a simple logarithmic trend fits the data very well, achieving an R-squared value of 0.99. The actual and estimated values of industry revenue according to this model are shown in Figure 8.

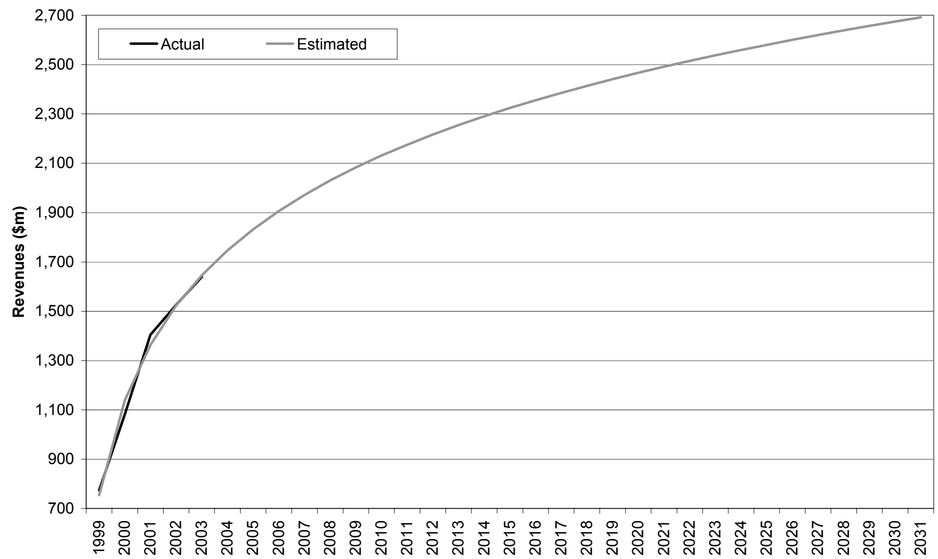
Table 4 New Zealand Cellular Industry Revenues.

Financial Year	Industry Revenues ($m)
1999*	773
2000	1,081
2001	1,404
2002	1,525
2003	1,640

* Vodafone revenue for 1999 was for 5 months only and has been scaled up proportionally.

[19] If the structure of the market changes significantly by the time that cellular rights are to be renewed, this data definition will need to be modified accordingly.

Figure 8 Actual and Estimated Cellular Industry Revenues.



According to this model, cellular industry revenue in New Zealand will reach $2,175m by 2011 and $2,692m by 2031. This gives an annual average growth rate of 1.07% over the renewal period (2011 – 2031). This annual average growth rate is the value of *z* that will be used, in this approach, to determine the renewal prices of cellular spectrum rights.

It should be noted that if this approach is implemented to determine actual renewal prices, the estimation of *z* will be done several years from now, by which time additional data points will be available. These additional data points will improve the reliability of the estimate of *z*.

6.4.2. Implementing the Formula

Having estimated *z*, it is straightforward to apply the necessary formula(e) to calculate renewal prices of cellular spectrum rights. For example, if the renewal fee is to be paid as a lump sum five years prior to expiry, then equation 8 gives the appropriate price. That is,

$$\mathrm{V2} = \frac{[1+(1.07\%)]^{20}}{(1+r)^5} \times V1$$

Which implies:

$$\mathrm{V2} = \frac{1.2373}{(1+r)^5} \times V1$$

By way of example, suppose that a cellular spectrum right sold originally for $10m. Using an 11% discount rate, the price to be paid five years prior to expiry is:

$$V2 = \frac{1.2373}{(1 + 0.11)^5} \times 10{,}000{,}000$$
$$= \$7{,}342{,}875$$

Thus the renewal price is 27% lower than the original price paid. However, this apparent reduction is due to the discounting necessary if the renewal fee is paid five years prior to expiry. If the renewal fee were paid at expiry, the price would be $12,373,171, i.e., 24% higher than the original price paid.

6.5. Approach 2: Detailed Valuation Exercise

An alternative to the above formulaic approach is to undertake a more detailed valuation exercise to generate inputs to the discounted cashflow analysis. The result would be a valuation of those parts of each business that used a specified block of spectrum. This exercise would need to be carried out in close consultation with the firms that own cellular spectrum rights and would aim at establishing values for their expectations of future revenue flows during the renewal period, and of the associated outflows of cash. In particular, a detailed series of the net cashflows expected to occur during the renewal period would be constructed as a result of this consultation.

Essentially, this approach starts afresh and tries to determine the future value of a spectrum right from the firms' expectations of future cashflows. In particular, unlike the formulaic approach, this renewal price derived under this approach is not related to the original price paid for the right.

6.6. Comparing the Two Approaches

Both approaches have advantages and disadvantages. The main advantages of the first (formulaic) approach are that it is highly transparent and simple. It is therefore likely to be relatively acceptable to stakeholders both inside and outside the cellular industry. Secondary but nevertheless relevant advantages are that it uses the available market information (i.e. the original price) and depends on the aggregate performance of the sector rather than the specific performance of each firm in the past. The disadvantages stem largely from the simplicity of the method, which abstracts from many of the operational aspects of the cellular business.

The second (valuation exercise) approach is more flexible in the sense that it opens up a channel through which historical features of the market affect expectations about the future profitability of the cellular industry. On the other hand, it is also less transparent and more complicated process, and the consultation process allows existing right-holders to influence the renewal prices.

7. Multipoint Distribution Service (MDS)

Multipoint Distribution Service (MDS) is a wireless service using microwave frequencies that is generally used to provide television transmission services. In New Zealand this spectrum has received very little usage since the management rights licenses for frequencies between 2.3GHz and 2.4GHz were sold in 1990. The 12 management rights licenses sold for a total of around $1.4m, with prices ranging between $45,000 and $211,000.

7.1. Estimating *z*

For the MDS licenses there is a general lack of data from which we can make direct inferences about the trends in associated revenues. Instead we must rely on indirect measures as proxies for the relevant data. To this end, we have obtained from Statistics New Zealand a producer price index output series for the communications services grouping. This industry includes postal and courier services, and telecommunications services.[20]

Since all MDS licenses are nationwide, we do not need to perform any regional adjustments. We therefore apply Equation 8 directly:

$$\mathrm{V2} = \frac{(1 + \text{revenue growth})^{20}}{(1+r)^5} \times V1$$

The output PPI will serve as a proxy for the revenues derived from MDS. This series is shown in Figure 9. We can see that it has experienced rapid declines in recent years, with an annual average growth rate between 1994 and 2002 of -1.61%. This gives:

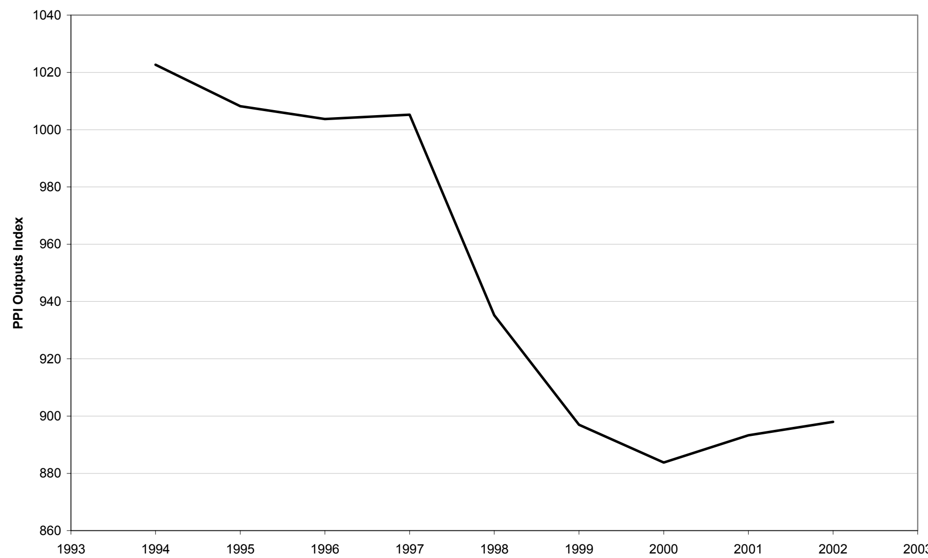
$$\mathrm{V2} = \frac{[1 + (-1.61\%)]^{20}}{(1+r)^5} \times V1$$

Which implies:

$$\mathrm{V2} = \frac{0.7228}{(1+r)^5} \times V1$$

[20] We had hoped to refine this data by using on the telecommunications services subgroup. However, due to commercial sensitivities, Statistics New Zealand is unable to release data for this subgroup alone.

Figure 9 Communications Services PPI Output Index.



Source: Statistics New Zealand

7.2. Implementing the Formula

To implement the formula, we need to decide the appropriate discount rate. As an example, suppose that an MDS license sold for $100,000 at the last auction and the appropriate discount rate is 11%. The renewal fee would be calculated as:

$$\text{V2} = \frac{0.7228}{(1+0.11)^5} \times V1$$

$$= 0.42895 \times V1$$

$$= \$42{,}895$$

Hence the renewal fee will be $42,895, 57% lower than the original price. Paid at the outset of the renewal period, the fee would be $72,280, 28% lower than the original price.

8. Other Spectrum Rights and Licenses

The previous sections have discussed pricing methodologies for spectrum rights and licenses applicable to radio, television, cellular, and MDS. In principle, a similar methodology could be used to calculate renewal prices for any type of spectrum license or right that is used for commercial purposes, such as Distributed Music Services (DMS). In this section we outline in general how this could be done.

The main assumptions of our formulaic approach to the discounted cashflow analysis are that the growth rates of revenues and costs are stable over time, and that profit margins are constant over time. Mature industries that are not subject to significant technological change are most likely to fit within these assumptions. In such cases, it should be relatively straightforward to apply the same formulas to calculate renewal prices. The main task is to estimate the variable z, the growth rate of cashflows during the relevant renewal period. The following steps outline the process to be followed:

1. Collect data on the relevant industry revenues.

2. Identify the drivers of revenues, collect the relevant data, and form regression models.

3. Use the regression models to forecast industry revenues from the present date until the end of the renewal period.

4. Calculate the annual average growth rate of revenues during the renewal period. This is the value of z.

5. Apply the appropriate formula (equation 8 or 11) to calculate the renewal fee.

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Appendix 1: Territorial Authority Annual Population Growth Rates

The table below summarises the annual population growth rates between 2001 and 2021 for each territorial authority (city or district) in New Zealand. These are used to regionalise the renewal fee formulae for television and radio spectrum licences (in accordance with Equations 16 and 17 respectively).

New Zealand Territorial Authorities	Annual Pop growth (2001 - 2021)	New Zealand Territorial Authorities	Annual Pop growth (2001 - 2021)
Far North District	0.69%	Rangitikei District	-1.07%
Whangarei District	0.41%	Palmerston North City	0.62%
Kaipara District	-0.20%	Tararua District	-0.96%
Rodney District	2.04%	Horowhenua District	-0.18%
North Shore City	1.37%	Kapiti Coast District	1.30%
Waitakere City	1.50%	Porirua City	0.13%
Auckland City	1.57%	Upper Hutt City	-0.49%
Manukau City	1.60%	Lower Hutt City	-0.07%
Papakura District	0.84%	Wellington City	0.61%
Franklin District	1.43%	Masterton District	-0.33%
Thames-Coromandel District	0.92%	Carterton District	-0.22%
Hauraki District	-0.62%	South Wairarapa District	-0.35%
Waikato District	0.34%	Tasman District	0.87%
Matamata-Piako District	-0.48%	Nelson City	0.81%
Hamilton City	1.14%	Marlborough District	0.58%
Waipa District	0.65%	Kaikoura District	0.00%
Otorohanga District	-0.43%	Buller District	-0.76%
South Waikato District	-1.10%	Grey District	-0.60%
Waitomo District	-0.54%	Westland District	-0.53%
Taupo District	0.39%	Hurunui District	0.61%
Western Bay of Plenty District	1.56%	Waimakariri District	1.55%
Tauranga District	1.89%	Christchurch City	0.46%
Rotorua District	0.39%	Banks Peninsula District	0.36%
Whakatane District	-0.07%	Selwyn District	1.78%
Kawerau District	-1.50%	Ashburton District	-0.10%
Opotiki District	0.50%	Timaru District	-0.39%
Gisborne District	-0.33%	Mackenzie District	-0.27%
Wairoa District	-1.00%	Waimate District	-1.08%
Hastings District	0.08%	Chatham Islands Territory	0.00%
Napier City	-0.02%	Waitaki District	-0.96%
Central Hawke's Bay District	-0.43%	Central Otago District	-1.00%
New Plymouth District	-0.30%	Queenstown-Lakes District	2.51%
Stratford District	-1.10%	Dunedin City	0.21%
South Taranaki District	-0.88%	Clutha District	-0.73%
Ruapehu District	-1.07%	Southland District	-0.77%
Wanganui District	-0.35%	Gore District	-1.04%
		Invercargill City	-0.75%

Appendix 2: Regional Annual Population Growth Rates

The table below summarises the annual population growth rates between 2001 and 2021 for each region in New Zealand. These are used to regionalise the renewal fee formulae for television and radio spectrum licences (in accordance with Equations 16 and 17 respectively).

New Zealand Geographic Areas	**Annual Pop growth (2001 - 2021)**
Regions	
Northland Region	0.45%
Auckland Region	1.54%
Waikato Region	0.51%
Bay of Plenty Region	1.11%
Gisborne Region	-0.33%
Hawke's Bay Region	-0.06%
Taranaki Region	-0.51%
Manawatu-Wanganui Region	-0.04%
Wellington Region	0.32%
Tasman Region	0.87%
Nelson Region	0.81%
Marlborough Region	0.58%
West Coast Region	-0.63%
Canterbury Region	0.51%
Otago Region	0.21%
Southland Region	-0.80%
Main Islands	
North Island	0.88%
South Island	0.33%
New Zealand	0.75%

Appendix 3: Effects of Averaging Base Prices

In this appendix we show the effects on total revenue of applying different types of averaging to original auction prices, as discussed in section 4.6.1.

1. Weighted Averaging

Suppose we have *n* spectrum licenses of a similar type (radio, television, etc). Let p_i denote the price paid for license *i* and let x_i denote the corresponding population coverage. The total revenue from auctioning these licenses was

$$R = \sum_{i=1}^{n} p_i$$

Now suppose we calculate a weighted average per-capita price as:

$$\bar{p} = \frac{\sum_{i=1}^{n} x_i \left(\frac{p_i}{x_i} \right)}{\sum_{i=1}^{n} x_i}$$

$$= \frac{\sum_{i=1}^{n} p_i}{\sum_{i=1}^{n} x_i}$$

If all *n* licenses are renewed at this constant price per capita, the total revenue from renewal will be:

$$\bar{R} = \sum_{i=1}^{n} \bar{p} x_i$$

$$= \frac{\sum_{i=1}^{n} p_i}{\sum_{i=1}^{n} x_i} \sum_{i=1}^{n} x_i$$

$$= \sum_{i=1}^{n} p_i$$

$$= R$$

Thus, if all spectrum licences are renewed at a weighted-average price per capita, total revenue will be unchanged. If due to price increases one or more licenses are not renewed, revenue will fall. However, this fall in revenue needs to be evaluated against the likely revenue received at auction for the un-renewed licenses. If the per-capita price achieved at auction falls short of $\bar{p}$, total revenue will fall. It seems quite likely that this would be the case. License holders would not choose to go to auction if they expected to pay more than the renewal fee.

2. Unweighted Averaging

Suppose instead that we implement a standard unweighted average of the per-capita auction prices. The outcome in this case is dependant on the set of licenses that we include in the average. There seem to be two sensible approaches. First, we could say that all technically identical licenses, such as those shown in Table 2, should have identical per-capita prices. Since all cover the same population, this is equivalent to simply taking the average of the selling prices. For the licenses in Table 2, this amounts to $9961. However, it is obvious that applying this methodology cannot directly lead to an increase in total revenue, and will likely lead to a decrease. If all the holders of the seven licenses in Table 2 agree to buy at this price, total revenue will be exactly the same as before. In the likely outcome that some of the holders with lower willingness to pay drop out of the market, total revenue will fall.

An alternative approach involves expanding the set of licenses upon which we impose equality of per-capita prices. This could be done at either a regional or a national level. In either case the mechanics are the same. It turns out that the outcome of this approach in terms of total revenue raised is *a priori* ambiguous, and could actually lead to a reduction in total revenue.

This is most easily illustrated by imagining that we have two licenses (for the same technology, e.g. radio) that cover different populations and sold for different prices. Similar results with greater algebraic complexity arise for greater numbers of licenses. The same results also apply if any other basis (instead of population covered) is used to standardize the prices.

Let p_1 and p_2 be the original prices paid and x_1 and x_2 be the populations covered (or whatever other basis is deemed appropriate). Without loss of generality we can assume that $x_1 \geq x_2$. The original amount of total revenue is $R = p_1 + p_2$. The average price per capita of these two licenses is

$$\bar{p} = \frac{\frac{p_1}{x_1} + \frac{p_2}{x_2}}{2}$$

The normalized prices for the two licenses are therefore

$$\begin{aligned} \bar{p}_1 &= \bar{p}x_1 \\ \bar{p}_2 &= \bar{p}x_2 \end{aligned}$$

The new level of total revenue is

$$\begin{aligned} \bar{R} &= \bar{p}_1 + \bar{p}_2 \\ &= \bar{p}(x_1 + x_2) \\ &= \left(\frac{\frac{p_1}{x_1} + \frac{p_2}{x_2}}{2} \right)(x_1 + x_2) \end{aligned}$$

Total revenue therefore increases following this adjustment if $\bar{R} > R$, which implies

$$\left(\frac{\frac{p_1}{x_1} + \frac{p_2}{x_2}}{2} \right)(x_1 + x_2) - (p_1 + p_2) > 0$$

Rearranging,

$$\tfrac{1}{2}(x_1 - x_2)\left(\frac{p_2 x_1 - p_1 x_2}{x_1 x_2} \right) > 0$$

Since x_1 and x_2 are both positive and since by assumption $x_1 \geq x_2$, this is positive if

$$p_2 x_1 > p_1 x_2$$

Or,

$$p_1 < \frac{x_1}{x_2} p_2$$

There is no *a priori* reason to expect this condition to be satisfied or not, and thus we cannot be sure if total revenue will increase or decrease following an adjustment to equalize the per-capita prices. Indeed, since $x_1 \geq x_2$, a necessary condition is that $p_1 < p_2$, which means that the original price for a license which covered a larger population must be lower than the price for the other license. We would not generally expect this to be the case, so it seems quite likely that total revenue will fall.

It should also be noted that these calculations also assume that the licenses are willingly bought at the new prices. If prices rise significantly, it is likely that there will be some reduction in demand for them, and this may offset any increase in revenue that is achieved.

Appendix 4: Equivalence of Constant Margin Assumption with the Equal Revenue and Cost Growth Assumption

We claim that assuming a constant profit margin over time is equivalent to assuming that revenue and costs grow at the same rate. In this appendix we provide a formal proof.

First, define the profit margin (m_i) on revenue in period i as:

$$m_i = \frac{R_i - C_i}{R_i}$$

where R_i = revenue in period i

C_i = cost in period i

Now, assume that revenues grow each year by some constant factor a and costs grow by some constant factor b. Then for any period n years from now, the profit margin equals:

$$m_{i+n} = \frac{R_{i+n} - C_{i+n}}{R_{i+n}}$$

$$= \frac{(1+a)^n \times R_i - (1+b)^n \times C_i}{(1+a)^n \times R_i}$$

If we assume that revenues and costs grow at the same rate each year, we have $a = b$. Substituting into the equation above yields:

$$m_{i+n} = \frac{(1+a)^n \times R_i - (1+a)^n \times C_i}{(1+a)^n \times R_i}$$

$$= \frac{(1+a)^n \times (R_i - C_i)}{(1+a)^n \times R_i}$$

$$= \frac{R_i - C_i}{R_i}$$

$$= m_i$$

Appendix 5: Pricing formulae to renew an existing *n*-year license for a further *m* years

In this appendix we derive the necessary adjustment to our formula to apply to renewals of *n*-year licenses for a further *m* years.

The value of the original license (covering *n* years) is given by:

$$V_1 = \sum_{i=1}^{n} \frac{CF_i}{(1+r)^{i-1}}$$

Since CF_i grows at the constant rate *z*, $CF_i = (1+z)^{i-1} CF_0$, where CF_0 is the cash flow in the initial period. Also, let

$$\beta = \frac{1+z}{1+r}$$

Then we can write:

$$V_1 = \sum_{i=1}^{n} \frac{(1+z)^{i-1} CF_0}{(1+r)^{i-1}}$$

$$= CF_0 \sum_{i=1}^{n} \beta^{i-1}$$

If the renewal period is for *m* years, the value at renewal, V_2, is given by:

$$V_2 = \sum_{i=n+1}^{n+m} \frac{CF_i}{(1+r)^{i-(n+1)}}$$

$$= CF_0 \sum_{i=n+1}^{n+m} \frac{(1+z)^{i-1}}{(1+r)^{i-(n+1)}}$$

$$= (1+z)^n CF_0 \sum_{i=1}^{m} \frac{(1+z)^{i-1}}{(1+r)^{i-1}}$$

$$= (1+z)^n CF_0 \sum_{i=1}^{m} \beta^{i-1}$$

Hence,

$$\frac{V_2}{V_1} = (1+z)^n \left(\frac{\sum_{i=1}^{m} \beta^{i-1}}{\sum_{i=1}^{n} \beta^{i-1}} \right)$$

Multiplying the numerator and denominator of the expression in brackets by (1 – β) gives:

$$\frac{\sum_{i=1}^{m} \beta^{i-1}}{\sum_{i=1}^{n} \beta^{i-1}} \times \frac{1-\beta}{1-\beta} = \frac{\sum_{i=1}^{m} \beta^{i-1} - \sum_{i=1}^{m} \beta^{i}}{\sum_{i=1}^{n} \beta^{i-1} - \sum_{i=1}^{n} \beta^{i}}$$

$$= \frac{\sum_{i=1}^{1} \beta^{i-1} + \sum_{i=2}^{m} \beta^{i-1} - \sum_{i=1}^{m-1} \beta^{i} - \sum_{i=m}^{m} \beta^{i}}{\sum_{i=1}^{1} \beta^{i-1} + \sum_{i=2}^{n} \beta^{i-1} - \sum_{i=1}^{n-1} \beta^{i} - \sum_{i=n}^{n} \beta^{i}}$$

Since the middle two terms in the numerator and denominator both cancel, we therefore have:

$$\frac{\sum_{i=1}^{m} \beta^{i-1}}{\sum_{i=1}^{n} \beta^{i-1}} = \frac{\sum_{i=1}^{1} \beta^{i-1} - \sum_{i=m}^{m} \beta^{i}}{\sum_{i=1}^{1} \beta^{i-1} - \sum_{i=n}^{n} \beta^{i}} = \frac{1-\beta^m}{1-\beta^n}$$

From which it follows that:

$$\frac{V_2}{V_1} = (1+z)^n \left(\frac{1-\beta^m}{1-\beta^n} \right)$$

Substituting for β, and since renewal fees are levied five years prior to expiry of existing rights (rather than at the time of expiry), this becomes:

$$V_2 = \frac{(1+z)^n}{(1+r)^5} \times V_1 \times \left(\frac{1-\left((1+z) \big/ (1+r) \right)^m}{1-\left((1+z) \big/ (1+r) \right)^n} \right)$$