

Howell, Bronwyn; Potgieter, Petrus H.

## Conference Paper

# Using spectrum set-asides to address distributional objectives: lessons from Canada, New Zealand, South Africa and the United States

24th Biennial Conference of the International Telecommunications Society (ITS): "New bottles for new wine: digital transformation demands new policies and strategies", Seoul, Korea, 23-26 June, 2024

### Provided in Cooperation with:

International Telecommunications Society (ITS)

*Suggested Citation:* Howell, Bronwyn; Potgieter, Petrus H. (2024) : Using spectrum set-asides to address distributional objectives: lessons from Canada, New Zealand, South Africa and the United States, 24th Biennial Conference of the International Telecommunications Society (ITS): "New bottles for new wine: digital transformation demands new policies and strategies", Seoul, Korea, 23-26 June, 2024, International Telecommunications Society (ITS), Calgary

This Version is available at:

<https://hdl.handle.net/10419/302463>

### Standard-Nutzungsbedingungen:

Die Dokumente auf EconStor dürfen zu eigenen wissenschaftlichen Zwecken und zum Privatgebrauch gespeichert und kopiert werden.

Sie dürfen die Dokumente nicht für öffentliche oder kommerzielle Zwecke vervielfältigen, öffentlich ausstellen, öffentlich zugänglich machen, vertreiben oder anderweitig nutzen.

Sofern die Verfasser die Dokumente unter Open-Content-Lizenzen (insbesondere CC-Lizenzen) zur Verfügung gestellt haben sollten, gelten abweichend von diesen Nutzungsbedingungen die in der dort genannten Lizenz gewährten Nutzungsrechte.

### Terms of use:

*Documents in EconStor may be saved and copied for your personal and scholarly purposes.*

*You are not to copy documents for public or commercial purposes, to exhibit the documents publicly, to make them publicly available on the internet, or to distribute or otherwise use the documents in public.*

*If the documents have been made available under an Open Content Licence (especially Creative Commons Licences), you may exercise further usage rights as specified in the indicated licence.*

# Using spectrum set-asides to address distributional objectives: lessons from Canada, New Zealand, South Africa and the United States

Bronwyn E. Howell and Petrus H. Potgieter\*

June 2024

## Abstract

This paper critically examines the effectiveness of spectrum set-asides as a policy tool to address distributional objectives in telecommunications across four diverse national contexts: Canada, New Zealand, South Africa, and the United States. Spectrum allocation is a crucial factor for the provision of telecommunications services and by extension, for citizens' participation in the digital economy. While economic theory supports auction-based allocations to maximize market efficiency, set-asides aim to facilitate access for disadvantaged groups or to stimulate competition. This study employs case studies from the selected countries to evaluate the impact of these set-asides on market efficiency, competition, and economic development.

In Canada, set-asides intended to encourage new market entrants have led to higher spectrum costs and inefficiencies due to speculative behaviour. In New Zealand, allocations to the indigenous Māori population have raised concerns over long-term sector efficiency and capital accessibility. South Africa's policy mandates spectrum allocations to entities with significant ownership by historically disadvantaged persons, with mixed outcomes on market dynamics and social equity. Meanwhile, the United States' approach includes grants rather than direct spectrum set-asides, offering a potentially less distortive model. The findings suggest that while set-asides can support social objectives, they often introduce inefficiencies and fail to achieve the desired economic outcomes. The paper concludes by discussing the implications for future spectrum policy, advocating for careful consideration of the trade-offs between equity and efficiency in spectrum management.

## Keywords

Spectrum Allocation; Telecommunications Policy; Digital Economy; Market Efficiency; Competitive Supply; Economic Development; Regulatory Strategies

## 1 Introduction

Access to specific radio spectrum frequencies is a necessary but not sufficient requirement for the provision of telecommunications services. Access to telecommunications services is likewise a necessary but not sufficient requirement for citizens to engage in the digital economy and society more generally. As the

---

\*School of Management, Victoria University of Wellington, New Zealand, [bronwyn.howell@vuw.ac.nz](mailto:bronwyn.howell@vuw.ac.nz) and Institute for Technology and Network Economics; Department of Decision Sciences, University of South Africa, Pretoria, [php@grensnet.com](mailto:php@grensnet.com) or [potgiph@unisa.ac.za](mailto:potgiph@unisa.ac.za) and Institute for Technology and Network Economics; respectively.

digital economy increases in importance, and the greater becomes the reliance of citizens on digital sources of information and communication in order to participate fully in society, the more important it has become for regulators and policy-makers to ensure that all citizens have access to affordable telecommunications services of sufficient quality to ensure this participation. A long-standing consensus internationally is that for the most part, ensuring conditions exist for the competitive supply of services offers the best means of achieving this objective (International Telecommunications Union 2015; Jamison 2024). This necessitates the allocation of rights to use spectrum in a manner supporting the most efficient long-run production of telecommunications services - typically by way of auction or some other price or value-discovering mechanism (Cave and Valletti 2000; Pogorel 2007; El-Moghazi and Whalley 2021). Assisting disadvantaged individuals and communities to these services is then best facilitated using income subsidies - for example, the United States Affordable Connectivity Program (Horrigan 2024).

Nonetheless, in many jurisdictions, spectrum rights allocations can deviate from this principle, for a variety of reasons. On the one hand, spectrum rights managers and regulators may package and release spectrum rights with a view to achieving a particular set of structural arrangements in the sector. For example, bundles of rights may be reserved for new entrants, and sold at discounted rates to encourage new entry. Arguably, this may not be inconsistent with increased sector efficiency, if it is considered there are insufficient operators to achieve a workably competitive market. On the other hand, bundles may be reserved in order to facilitate specific groups (firms, individuals or others) to become telecommunications operators as a distributional matter. For example, rights to provide services in specific geographic locations (e.g. remote, rural and tribal) may be reserved at low or no cost for residents in that location as it is presumed that their strong incentives to obtain coverage will lead to service provision sooner in these areas than if the rights were obtained by service providers with rights to provide services first in more populous or less-costly areas. Furthermore, reserving bundles of rights for historically disadvantaged populations has been proposed as a means of supporting their economic and/or social development. Examples of this include the historic granting of radio and television broadcasting spectrum rights to indigenous and minority communities to facilitate communication in their native languages (e.g. in New Zealand in 1990 (Ministry of Business, Innovation and Employment n.d.)). However, this does not address the current situation where digital convergence means that increasingly radio and television content is streamed over standard broadband connections rather than dedicated broadcast spectrum. Moreover, a new set of claims on spectrum rights are coming from indigenous peoples, who assert that they never relinquished sovereignty over their spiritual embodiments in natural resources such as spectrum and waterways, so they should share in the ongoing governance of those resources (and the revenues derived from them) in current times (Cocullo 2022).

In this paper, we undertake case studies where spectrum has been set aside for specific (disadvantaged) groups (Canada, New Zealand) or specific spectrum transfers can be made only if the new owners exhibit a specific proportion of a disadvantaged group (South Africa). We also consider the United States, where eligible tribal entities may bid for grants to provide connectivity to their territories, rather than reserving spectrum for, or transferring it to them to manage. We begin with a short discussion of the economics of spectrum utilization, followed by a review of the literature on the economic effects of spectrum set-asides. Next we discuss the literature on spectrum allocation in pursuit of objectives other than the efficient operation of telecommunications markets. We then present the case studies: Canada, where set-asides to encourage market entry have been unsuccessful; New Zealand, where allocations to the indigenous population threatens overall sector efficiency and may prove not to deliver the aspired economic development objectives due to difficulties in accessing capital; the United States, where a proposal (not passed) to allocate spectrum to indigenous populations in specific territories would have been less distorting than the New Zealand arrangements, and where federal grants for funds to develop network infrastructure and services appear better suited to addressing both economic and social objectives; and finally South Africa, where mandates regarding the ethnic composition of the owners of companies bidding for spectrum has had mixed outcomes.

## 2 Literature Review

Electromagnetic spectrum is essential to the operation of a modern digital economy as it enables the wireless transmission of digital information. Demand for spectrum is derived from demand for the applications that use the information digitally encoded and transmitted using the spectrum. Applications include radio and television broadcasting, cellular voice telephone connectivity and now the vast array of internet applications that make use of mobile broadband connectivity. They also include any spiritual or cultural associations (i.e. “cultural applications”) that indigenous people may have with spirits or ancestors believed to inhabit the airwaves.<sup>1</sup> Absent demand for these applications, the spectrum has no meaningful economic or social value. Hence, the development and growth in use of these applications determines its value.

### 2.1 Contestability

For the most part, spectrum used in an electronic engineering sense is a scarce economic resource. Applications (such as 5G mobile technology) are developed to make use of specific frequency bands allocated using an international standards-setting exercise undertaken by the International Telecommunications Union. National governments define and allocate blocks of frequencies to users within their geographic territories. The specific allocation process varies (more later) but this allocation process ensures that the users have the right to exclusive use of their blocks without fear that transmissions by unauthorised users, or those of the owners of adjacent blocks, do not interfere with their transmissions. Thus rights holders (and by extension their customers) have the assurance that they can develop and deploy networks (i.e. the physical technology to operate a communications network service) and applications (e.g. broadband services, voice telephony, and for their end users, applications, portals, exchange platforms and the like) and derive economic benefits from them. As demand for application use increases, demand for use of the spectrum within the allocated block increases. The rights holders can develop new technologies to make better (more efficient) technical use of their allocations, but eventually they must acquire more spectrum or face a degradation in the quality of service they can offer their end users. The economics of spectrum deployment mean that it is most efficient (lower cost) if the spectrum acquired is in blocks adjacent to those already held. While adaptations can be made to use non-adjacent blocks, these impose additional costs. Hence spectrum allocation must be done with awareness of both current and anticipated future usage patterns if the contestable spectrum is to be used most efficiently. For example, the ITU recommends that 5G spectrum blocks span at least 100MHz for each user to cater for interference minimisation and address future demand growth efficiently.

Spectrum used for cultural purposes does not exhibit the same economic scarcity as technically its use for one (non-engineering) purpose does not reduce its availability for other similar applications. However, some cultural entities wishing to exercise control over spectrum in the geographic territories where they exercise other control rights (e.g. the 576 government-recognised tribal entities in the USA) require exclusivity from other potential uses of the airwaves that compromise the electromagnetic spectrum in order to satisfy their cultural application needs (for example, not disturbing embedded spiritual beings) (Blackwater, Murtazashvili, and Weiss 2023).

### 2.2 Valuation

For spectrum to yield economic value, there must also be significant investment in the infrastructure required to build the base communications networks as well as the communications applications overlaying them to make the network itself useful to end users. These investments are very large, fixed, required to be fully deployed before any revenue can be derived, and for the most part, sunk (i.e. cannot be recovered once spent, such as the holes in the ground dug to bury cables, the towers built to deploy antennas, software to

---

<sup>1</sup>Cameron (2013) writes, with reference to radio-frequency spectrum, that “Māori interests extend beyond the physical into the metaphysical, and that proper Treaty compliance must consider these interests alongside concepts more familiar to the European mind.”

operate the communications applications etc.). For these reasons, it is generally not economically efficient to have more than a handful of operators providing communications network services. Furthermore, for modern, 5G systems, there are considerable economies of scale and scope that make it highly beneficial for network operators to have access to a wide range of different spectrum bands to be able to customise different service offerings for a wide range of different applications for the same customers. For this reason, incumbent operators with existing spectrum bands and services (including towers, software, backhaul access arrangements, internet exchange and data centre facilities, etc.) have been able to deploy applications using recently-allocated spectrum for 5G services more quickly and more cost-effectively than new entrants. Consequently, the prevalent trend in the past few years has been for consolidation of telecommunications network providers. This contrasts strongly to twenty or thirty years ago, when it was feasible for new network operators to enter many markets, where there were efficiency gains to be made from competition between operators, in the price, quality and range of services made available.

These factors have significant bearing on the question of who should be allocated the blocks of spectrum made available, and how the allocation process should take place. Since the 1980s, there has been a widely agreed international consensus that the most efficient way to allocate spectrum is via an auction or some other contestable bidding process that reveals the value placed on spectrum by those seeking to use it, based on their estimations of how profitable they expect use of it to be for them, given the applications they seek to use it for. The national spectrum management entities (e.g. the FCC in the USA, MBIE in New Zealand, ISED in Canada and ICASA in South Africa) ultimately however have the power to decide how spectrum blocks will be comprised and allocated. While in all four countries, auction has been the preferred allocation method, in some cases, choices can be made to “set aside” or reserve some blocks for specific purposes. These set-aside blocks may not be auctioned, but instead be reserved for specific classes of potential owners in order to achieve some specific purpose. They may also have different terms and conditions associated with them, which separates them from the commercial, auctioned blocks. For example, in the early days of mobile telecommunications, it was common for such blocks to be reserved for new entrants so as to mitigate any effects of market dominance observed amongst incumbents. These blocks could, for example, be sold at a discount to equivalent prices paid by the incumbent operators for their spectrum (e.g. the Hautaki spectrum reserve that enabled third operator 2 Degrees to enter the New Zealand market in the mid 2000s (B. Howell and Tang 2023)). They can also be reserved for specific distributional purposes - for example, radio broadcasting frequencies reserved in New Zealand in 1990 were made available only to broadcasters committed to nurturing the indigenous Māori language - something which the Government had a specific contractual obligation to facilitate (Ministry of Business, Innovation and Employment n.d.; B. Howell 2024).

### 2.3 Set-asides

However, set-asides are not economically neutral. The literature clearly indicates that they distort spectrum auctions. Firstly, the total spectrum available to commercial operators is reduced compared to the total in the relevant band, creating “artificial scarcity” which likely results in higher auction prices (Crandall and Ingraham 2007). Additionally, reserved spectrum (if sold) tends to sell at lower prices due to fewer bidders (Cramton et al. 2011). Moreover, commercial operators often engage strategically with eligible bidders for the reserved spectrum, making it uncertain whether the parties intended by the spectrum authority are the ones who ultimately acquire it (Cramton, Ingraham, and Singer, n.d.). Frequently, set-aside spectrum is acquired by inefficient firms; if the conditions on set-aside spectrum prevent it from being traded in secondary markets, then this inefficiency cannot be easily corrected (Hoppe, Jehiel, and Moldovanu 2006)

There is ongoing debate about whether higher spectrum costs for operators translate into higher service prices for consumers (Koutroumpis and Cave 2018). In competitive markets, higher demand suggests a greater willingness to pay for spectrum. The bidding criteria require that the expected average cost surpasses the spectrum price paid. Since the marginal cost is zero, the average cost is the annualized fixed cost divided by quantity, which is positive initially (at entry or renewal) but zero subsequently. The GSMA argues

that higher spectrum prices are generally passed on to consumers, leading to reduced consumer welfare as prices reflect average costs, including higher spectrum fees (Global System for Mobile Association 2017). However, (Cambini and Garelli 2017) found through empirical research on firms in 24 countries over a decade that spectrum availability and fees do not correlate with mobile operators' revenues, supporting the hypothesis that operators consider spectrum fees as sunk costs when setting service prices – the “sunk cost hypothesis.” Regardless of the sunk cost hypothesis, the fact remains that if there is any chance that the set-aside spectrum will come on the market eventually, it is more valuable to the holder of adjacent blocks than to owners of non-adjacent blocks; to the extent that potential owners are known ex ante, or that the reserved spectrum may come on the market with different terms and conditions than the auctioned spectrum, then it becomes much harder for the relevant parties to accurately evaluate their options to buy at auction or wait for (or even influence) subsequent secondary trading.

## 2.4 Ownership

It has been argued by some that giving spectrum rights to economically disadvantaged communities in specific geographic locations can serve to redress economic, social and digital divides. The rationale is that the spectrum can be used to attract service provision, confer profits from network ownership and upskill individuals in network engineering skills within disadvantaged communities (Cocullo 2022; Blackwater 2023). However, telecommunications network operation requires substantial additional capital as well as spectrum holdings. It is not clear where already financially-disadvantaged communities will raise this additional capital to deploy networks with any spectrum they may own. It is also not clear that network ownership is the most profitable or useful way of investing their scarce resources, given the decreasing network operation revenues and profits in recent years, in an ecosystem where application providers have proven to be both most profitable and prospective participants. While technical skills in network engineering may be of some use, with only a limited number of networks ever likely to serve an area, skilled employment growth is far more likely to occur in creating and using applications using the networks, not network operation in and of itself. For this reason, it is not axiomatic that spectrum ownership is necessary for these communities to participate in the digital economy or that spectrum ownership alone will close digital or skills divides.

By way of example, spectrum made available to an indigenous community in New Zealand in 1999 was intended to address these issues. The spectrum was leased in exchange for shares in a new network operator. However, when the network operator required new capital to expand, the indigenous community could not participate. The shares were used as collateral for a loan by the new investors initially to prevent the indigenous shareholding from decreasing, but inability to service the loan saw the shareholding gradually decrease over time anyway as shares were exchanged to pay loan debts. There was negligible evidence that the community developed any new digital skills from this ownership vehicle specifically; several millions of dollars of additional government grants were provided for digital skills training under other schemes. Over twenty years later it was still being claimed that additional spectrum ownership would increase digital skills still assessed to be lacking in the relevant community (B. Howell 2024).

## 2.5 Non-economic considerations

Since the adoption of the United Nations Declaration on the Rights of Indigenous Peoples in 2007, establishing a universal framework of minimum standards for the survival, dignity and well-being of indigenous peoples, there has been renewed interest in the extent to which it should be recognised by the nation states in which they live that they should continue to exercise autonomy and “sovereignty” over, particularly, natural resources associated with historic cultural use. Where these peoples occupy a distinct geographic territory so that the specific resources can be “ring-fenced” without depriving other citizens of their rights, and control within that territory transferred to the relevant indigenous leadership entities, then it may be feasible to allow this to occur. Blackwater, Murtazashvili, and Weiss (2024) have however argued that there is an economic case for polycentric spectrum management involving tribal/indigenous interests using case studies

from the United States, Guatemala, Canada, and New Zealand.

The indigenous leadership can then make decisions about the resources' use that meets their criteria, including any cultural preferences, without necessarily affecting the uses of the resource in other areas, which can continue to be governed according to the nation states' preferences. Spectrum governance could fit into this category, as the rights can be defined in relation to specific geographies. Small scale need not necessarily be a factor - many nation states (e.g. Luxembourg, Andorra, Monaco) cover much smaller territories than some Indian Nations recognised by the United States (e.g. the Navajo and Choctaw Nations). While the costs of independent governance of spectrum and application use, specifically agreements for the exchange of services into and out of the territory and with other network operators, may be considerable, this need not diminish the desire of or ability for these peoples to make their own decisions about how the spectrum in their territories will be used. The important issue is that they make the decisions about how it is used themselves - even if that means their choices are motivated by pursuing objectives other than network efficiency (Blackwater, Murtazashvili, and Weiss 2023; Cocullo 2022).

### 3 Case Studies

We consider four case studies which have in common that they are mainly English-speaking (in government and business) and are relatively sparsely populated. They are also all nations which have been subject to extensive colonisation and settlement by Europeans. In all four, a political and moral imperative exists to recognise the rights and interests of the pre-settlement indigenous population.

#### 3.1 Canada

In Canada, there has been a long history of the use of spectrum set-asides to encourage the entry of a new nationwide operator to compete with the incumbents Rogers, Bell Canada and Telus, whose combined market share exceeds 85 percent. In recent auctions, significant blocks of spectrum have been reserved for non-incumbents (deemed those operators with less than ten percent market share). These cannot be resold to the incumbents for a considerable period of time following their sale. This has two immediate effects. First, the price of spectrum purchased by the incumbents is higher on average than could be expected in other countries, due to the artificial scarcity created, and this is presumed to flow through to retail prices for Canadian mobile services, which are amongst the highest in the OECD (albeit that comparisons are difficult due to the higher quality of the services provided - a strategic issue arising from the need for the incumbents to charge high prices to cover their higher costs)(Dippon, n.d.). Second, the fact that the reserved spectrum, sold initially at lower prices, can be resold after a given time period creates an incentive for purchases to be made with a view to speculation rather than network deployment (Cramton et al. 2011). As spectrum shortages become manifest when application use increases, the speculators may make more from ultimately reselling to the incumbents than if they had built a network themselves. This exacerbates the sector inefficiencies, and ensures prices remain higher for longer than necessary than if all spectrum had been sold to the incumbents initially. A third consequence is the fact that when the reserved spectrum does come on the market, it is likely not adjacent to the blocks held by the operators that most need it, leading to higher costs of deployment of it even when it does become available on the secondary market (Telus 2023).

Furthermore, even if those acquiring the reserve spectrum do undertake some (limited) network construction, they face disincentives to grow. First if they were to gain more than ten percent market share, they would no longer be eligible for lower-price spectrum offers. Second, other distortions in the Canadian regulatory space - notably, the regulated right for those with less than ten percent market share to roam on the incumbents' networks in areas where they do not have infrastructure - discourage small local operators from building out their network footprint to compete on a wider geographic or national basis (B. Howell, n.d.).

Consequently, despite good intentions, the Canadian spectrum set-asides have failed dismally at inducing new competition for the three incumbent operators. The net losers have been Canadian mobile service consumers, who have lacked a comprehensive range of different service qualities to choose from, and a range of prices observed for different service qualities as observed in other countries.

To date, there have been no specific allocations of spectrum for tribal areas. Spectrum blocks in Canada are divided up on a five-tier basis across national regional and local geographical boundaries. Some of these blocks will cover regions where specific indigenous communities reside, or areas of low population density which are more costly to serve. These blocks will not necessarily attract the same interest from operators than the blocks which will be more profitable. These blocks can be acquired by interested parties (e.g. a collective of residents in the areas) at low (or even no) cost, but simply acquiring the spectrum is insufficient to get network coverage. In these instances, further government subsidies may be necessary to fund network building.

## 3.2 South Africa

South Africa (SA) conducted a spectrum auction in 2022 that ended a spectrum-allocation drought of longer than 10 years. All bidders had to have at least 30% documented ownership by historically-disadvantaged persons (HDP, by current definition, the vast majority of the population) and achieve a level 4 score on the country's Broad-Based Black Economic Empowerment (BBBEE) which considers employment of and management by Black persons as well as procurement policies and other factors. This status has to be maintained throughout the period of the licence. It is important to note that the ownership score is calculated using a special accounting system whereby an institutional shareholder can be deemed to have HDP status even though many of its owners/shareholders/beneficiaries do not and vice versa. Some HDP criteria (e.g. sexual orientation or religious belief) are also not readily observable. The definition of Black is likewise a bit technical, being based on birth or descent and including (for example) persons of Chinese descent and (for all persons) those naturalised before 27 April 1994 but not after. Indigenous metaphysical concepts and traditions do not enter the picture at all.

The auction also applied spectrum caps as well as access, coverage and zero-rating obligations. One lot of 2 x 10 MHz in the 800 MHz band went unsold and is currently scheduled to be auctioned in 2025 (or later). It was put on auction with an outlandish coverage obligation of 99.8% of population and 95% of population in a list of underserved areas. All operators winning spectrum in the auction have to "connect public service institutions" including public schools, hospitals and tribal offices. A separate phase of the auction (the so-called "opt-in" part) was reserved for "Tier 2" operators i.e. the four qualifying smaller network operators. The qualifications for a "Tier 1" operator were carefully crafted to cover the two oldest and largest operators only.

During the opt-in round, operators were able to acquire spectrum in a simplified process to achieve a "minimum spectrum portfolio" and the process was designed (according to the invitation to apply<sup>2</sup>) to "ensure that South Africa is left with at least five (5) credible wholesale national operators after the spectrum assignment process." Two operators acquired spectrum in the opt-in process, raising R2.7 billion and all six participants acquired spectrum in the main round, raising R11.8 billion. Despite the continued efforts by the regulator to encourage smaller operators, calendar year 2023 saw the market share of both of the two largest mobile operators increasing. The main feature of the auction was therefore its careful design to ensure that smaller operators were able to obtain spectrum, especially Telkom (the partly government-owned incumbent) which desperately needed low frequency spectrum.

A new spectrum policy<sup>3</sup> was gazetted on 28 May 2024. The policy emphasis liberalisation (technology and

<sup>2</sup><https://www.ellipsis.co.za/wp-content/uploads/2021/12/ITA-Licensing-process-for-IMT-in-respect-of-the-provision-of-Mobile-Broadband-Wireless-Access-Services.pdf>

<sup>3</sup><https://www.ellipsis.co.za/wp-content/uploads/2024/02/Next-Generation-Radio-Frequency-Spectrum-for-Economic->



service neutrality), a use-it-or-lose it principle and spectrum sharing and trading (with the approval of the regulator, taking into account anti-competitive behaviour). Given the outcome of the 2022 auction, it seems unlikely that liberalised spectrum trading will result in the smaller operators purchasing spectrum from the two big ones. Indeed B. E. Howell and Potgieter (2022) describes the spectrum sharing arrangements that arose prior to the 2022 auction as a response to an inefficient initial allocation of radio frequency resources and the inability of decades of policy to create a challenger to the two dominant operators (B. E. Howell and Potgieter 2022).

The 2024 policy stipulates that “free basic access data” is to be provided through spectrum users to households for “community use” with the size of the allocation to be determined by the minister in consultation with the regulator. Given that the existing Universal Service Fund has been described as “an expensive failure with extremely limited impact” (Lewis 2020) it is not likely this mechanism will achieve its objectives. The regulator is also enjoined to reserve spectrum for the State Digital Infrastructure Company (SDIC) with distributional and transformational objectives.

### 3.3 New Zealand

New Zealand (NZ) pioneered the use of spectrum auctions in the late 1980s (Cave and Nicholls 2017) and led the world with the use of competition law alone to govern telecommunications markets. However, since the first radio broadcasting licences were privatised in 1990, there has been repeated challenges from representatives of the indigenous Māori people to the Government’s right to sell spectrum rights to private parties (B. Howell 2024). Māori interests contend that the Treaty of Waitangi signed on 6 February 1840 by the British Crown and local tribal leaders did not extinguish their customary rights to natural resources, and further that they have superior rights to be consulted and to participate in policy-making for the whole country as “partners with the Crown” in governing New Zealand.

There is considerable dissent about both of these claims. First, following a prolonged court process, culminating in a Privy Council ruling (the highest court of appeal at the time) it was ruled that the Crown did have the power to transfer both broadcasting licences and other assets (including spectrum) to private parties, albeit that the Crown did have an obligation to take measures to protect the Māori language. Second, a claim to the Waitangi Tribunal (set up to hear disputes under the Treaty, but whose rulings are recommendations only, and which have legal effect only if subsequently recognised by the Government – usually with legislation) in 1999 found (in a 2-1 majority) that Māori did have a claim to radio spectrum. The dissenting judge found that any such claim to natural resources would create a difficult precedent as this would in effect mean Māori could claim control everything in the natural world. The Government has never endorsed this Tribunal finding – indeed, on several occasions, it has been explicitly rejected that radio spectrum is subject to the Treaty at all. Hence the Crown claims exclusive title to all newly-created spectrum rights, and the authority to decide how to allocate them. Until 2020, this has always been by public auction for commercial spectrum blocks. Māori interest have continued to dispute all such auctions, citing the Waitangi Tribunal finding. However, the Crown has, with one exception, rejected this finding.

The one exception concerned 3G spectrum sold in 2000. At this stage, New Zealand had only 2 mobile operators and the Government wanted a third to enter. As a partial allowance to Māori interests, one block of spectrum was reserved to be sold (at a 5% discount on the auction price) to Māori interests. This spectrum was finally purchased in 2008, when the Māori interests (Hautaki Trust) partnered with Econet to form the third operator Two Degrees. Hautaki took shares in 2 Degrees in recognition of their contribution. However, over time as new capital was needed, the Hautaki share diminished, and by 2014 they surrendered their remaining shares to repay debt to the 2 Degrees holding company. Over this time, the Government contributed over 30 million dollars to Hautaki’s associated trusts and other Government funds to facilitate digital skills development amongst the Māori community (B. Howell and Tang 2023)

---

Development-2024.pdf It also announces a timetable for the shutdown of 2G and 3G services – still in wide use in rural areas, by connected devices and even by the urban public because of the cost of handsets.

In 2020, however, 5G spectrum was to be auctioned, but the COVID-19 pandemic intervened. The Crown made temporary administrative allocations to enable commercial investment, but indicated that 25% of the available spectrum would be reserved for a then-yet-to-be-established Māori Spectrum Authority (MSA) at no cost, pending a long-term agreement on Māori spectrum allocation. In February 2022, a Memorandum of Understanding (MOU) was announced, whereby the 5G spectrum allocation would become permanent and the MSA would be granted 20% of all future commercial spectrum allocations, again at no cost. Moreover, the MSA would be granted preferential consultation rights with the Crown spectrum management authority to develop future spectrum policy.

On face value, the MOU appears to give Māori very much what was recommended by the majority of the 1999 Waitangi Tribunal panel - absolute control of their share of spectrum, in perpetuity. The Māori spectrum is effectively perpetually renewable at no cost, in contrast to commercial holders, who must renegotiate terms with the Crown every 20 years if they are to keep the rights. The MSA in effect will act as a parallel spectrum authority alongside the Crown entity in relation to spectrum already owned, making its own decisions, contracts, rules etc. on how it will be used. Furthermore, the preferential consultation in effect allows the MSA to participate in future spectrum policy formulation - a form of "co-governance" of the asset.

Several difficulties, however, arise. First is that in New Zealand, all commercial spectrum rights cover the whole country: the MSA 5G spectrum will enable it to either compete directly with the commercial operators by providing its own services, or enter in agreements with them or their rivals for use of the spectrum, on different - and at present, non-transparent - terms. The MSA is not accountable to anyone other than its own tribal stakeholders for its decisions. This introduces significant uncertainty into the telecommunications sector. The Crown is no longer able to deliver its sector policy of fostering competitive and efficient markets. While the MSA has indicated it does not intend to use the 5G spectrum to support the entry of a fourth commercial operator (as Hautaki did with 2 Degrees), it is not bound to abide by this decision, nor is it accountable to or obliged to consult with anyone else in the sector if it does so. Consequently, it is now very much more difficult for operators to value future spectrum offers, This makes any price discovery mechanism for distributing future spectrum problematic. It likely underpins the reason for the Crown making the 2022 administrative allocations permanent rather than going to auction as originally intended. It also creates a higher administrative burden as all of the Crown, MSA and operators now have to take account of the additional dynamics of the MSA's mixed role. The New Zealand telecommunications sector thus becomes less efficient than any other jurisdiction without such an arrangement. These prices affect both Māori and non-Māori consumers, as they will all be purchasing their telecommunications services from the commercial operators, given the MSA has stated no current intention to offer competing services.

Second, the MSA's stated intentions to use the 5G spectrum to support the development of Māori services suggests that the spectrum will remain significantly underutilised compared to the commercial spectrum, due to the lack of either financial or human capital and complementary assets to develop the requisite network services. The commercial operators' shares were reduced by the amount given to the MSA. Spectrum shortages are inevitable in the long run, with similar situations arising as in Canada. The MSA can, like the spectrum speculators, sell its spectrum to the commercial operators, but the process for doing so will not be according to the transparent, accountable processes required of the Crown spectrum authority. This again adds uncertainty and potentially changes rivalry in the sector as the firm with the block adjacent to the MSA block has a lower-cost expansion option than the others.

Third, it is most unlikely that the MSA will be in a position to develop skills from owning spectrum if it cannot attract the additional investment capital to build its own networks (compared to the many millions of dollars already committed to Māori digital skills development via Hautaki and other entities). The recent purchase by the MSA of the company operating the towers distributing Māori radio and television transmission could on first assessment provide the potential to facilitate this. However, with broadcast audio and video rapidly moving to standard broadband networks, this appears to be an investment in a

sunset rather than frontier company. The towers may have value, but only if new capital can be attracted to invest in 5G infrastructure. Given that worldwide, telecommunications firms are divesting themselves of tower assets to get capital for 5G investment, it is not clear where this capital will come from. The benefit of the towers appears more likely to be of the form of real estate rental to other operators to put their equipment on the towers rather than the MSA operating the infrastructure itself.

Fourth, the spectrum policy consultation provision creates a significant conflict of interest, as it will be influencing the conditions in which both it and its commercial rivals will operate. The Crown has divested itself of any operation interests to avoid such a conflict, but the MOU reintroduces the very same conflict for the MSA. This is a significant governance concern given that the MSA is both a rival of the Crown as a spectrum management entity and the operators as a service provider.

Finally, as the MOU states that the Crown still does not accept the Waitangi Tribunal recommendations, Māori claims for spectrum are not finalised. The 1999 claimants wanted 50% of spectrum. All told, the New Zealand arrangements appear to give indigenous interests the control of spectrum aspired towards in the UNDRIP, but at considerable cost to telecommunications sector efficiency and Crown control of sector policy. It would be unfortunate if this precedent was followed elsewhere. Such arrangements may have been feasible if the Māori spectrum was geographically separate from other spectrum (as in the US and Canada). But where the rights compete, the consequences are likely disastrous.

### 3.4 United States

The United States (US) has a liberal approach to spectrum allocation. For the most part, spectrum is divided into blocks based on geographic coverage, and auctioned in a competitive process aimed at ensuring the most efficient arrangements. In a few limited circumstances, spectrum not assigned at auction has been made available under favourable terms to encourage coverage in (especially) rural and remote areas, in conjunction with the provision of additional funding to ensure that the complementary assets can also be acquired. In some instances, this has been of benefit for rural and indigenous communities including those covering tribal territories.

Set-asides for small operators have formed part of FCC auctions but with weak controls. In 2000 for example, AT&T Wireless obtained spectrum in a “closed” auction for small firms through a front company called Alaska Native (Connolly et al. 2018). The FCC has also, mandated by congress, promoted “diversity” in auctions through “bidding credits” which gives designated firms a discount on the price finally paid (as opposed to their winning bid).

In contrast to New Zealand, the United States recognises 574<sup>4</sup> distinct tribal territories with explicit powers to exercise local governance in a number of aspects of their economic and cultural lives. This could, potentially, facilitate the allocation and development of spectrum management regimes within the territories. This would allow local decisions to be made regarding the management and use of spectrum according to local tribal preferences, albeit at possibly higher cost than if a service was provided by an operator covering a large contiguous geographic territory, without compromising the decision-making and efficiencies of these non-tribal operators (Blackwater, Murtazashvili, and Weiss 2023).

In 2022, a proposal was made for legislation that would create preferential rights to spectrum covering tribal territories prior to commercial spectrum auctions taking place (S. 5321 — 117th Congress: DIGITAL Reservations Act<sup>5</sup>). The Bill did not pass into law, but does illustrate what could have been possible along similar lines to the New Zealand allocations, without the same degree of distortion in overall telecommunications markets.

First, it was not clear that the spectrum would be available at no cost - however, charges would be

---

<sup>4</sup><https://www.usa.gov/indian-tribes-alaska-native>

<sup>5</sup><https://www.govtrack.us/congress/bills/117/s5321>

set administratively not competitively. Second, these spectrum ownership arrangements would operate in conjunction with Federal grants making funds available from various appropriations to subsidise the deployment of infrastructure to render the spectrum usable to local residents. These grants typically come with terms requiring services to be deployed within a defined time. As Blackwater, Murtazashvili, and Weiss (2023) notes, there is no assurance that spectrum grants alone will address digital divides, as local decisions may militate against full deployment. The main justification for the bill was to recognise tribal sovereignty. Yet to the extent that deployment does occur, there are positive gains from skills development and application deployment available.

In the event, the bill did not pass, but the Federal grants did proceed, and indeed were arguably augmented by additional COVID-19 relief subsidies and the Affordable Connectivity Program. The desired service delivery outcomes alone could have been obtained, as spectrum ownership is not necessary for coverage to be deployed. If human capital development is indeed desired, then its acquisition can be made a specific delivery condition of the grants, alongside coverage. This suggests the most efficient means of achieving the wider societal end objectives, given the geographic constraints of the locations of tribal territories, is in place. This arrangement does not address the tribal sovereignty objective, but that could be achieved if a future version of the failed bill is subsequently passed.

## 4 Comparison

The following table summarises the presence of set-asides in spectrum allocation in the four cases.

Country	Set-asides for small operators	Set-asides for indigenous groups
Canada	Yes	No
New Zealand	No	Yes
United States	Yes	No
South Africa	Yes	Yes

First, we consider the effect of set-asides on the objective of encouraging competition by increasing the number effective national operators. In Canada and South Africa this has been perennial objective of regulation and auctions and the failure of this policy in Canada is well documented (Crandall and Ingraham 2007) whereas in South Africa it can only be inferred due to the paucity of recent auctions but a negative hypothesis is strongly supported by past policy in this regard (B. E. Howell and Potgieter 2022). Set-asides (like spectrum caps and use-it-or-lose-it principles) are particularly inefficient when a resale market is non-existent or badly developed (Cave and Nicholls 2017) as is the case in South Africa. The adverse effects of set-asides in Canadian auctions are particularly well documents. Fellows and Church (2023) examined the AWS-1 auction of 2008 and concluded that

- the increase in consumer surplus from the auction would have been greater by a factor of 6 to 8 times;
- growth in subscribers could have been a million more; and
- the drop quality-adjusted prices would have been even greater

had the set-asides not been in place. Where set-asides do have the effect of diversifying spectrum ownership, there is ample evidence that that adverse consequences follow. Woroch (2020) shows that more concentrated spectrum ownership in cellular market areas in the US are positive correlated with network coverage and quality (and with service uptake). In the EU, Guiffard et al. (2023) show that increasing spectrum concentration by allocating rights to three instead of four operators, enhances consumer welfare.

Second, we consider the effect of set-asides on the objective of increasing participation by indigenous and other disadvantaged groups. In South Africa the HDP and BBBEE auctions requirements apply across the board to all bidders and hence – other than completely excluding wholly foreign-owned operators – did not

have a major effect on the outcome of the 2022 spectrum auction. The regulator's annual state-of-the-sector report<sup>6</sup> provides data only on the yardstick of the number of Black top executives which varied between 28% and 40% in the most recent five years with no discernible trend.

US Federal grants making funds available from various appropriations to subsidise the deployment of infrastructure typically come with terms requiring services to be deployed within a defined time. In the putative case of spectrum allocated to tribal entities in the US, this would specifically address a significant problem with the New Zealand arrangements for indigenous spectrum ownership that focus on spectrum alone. With concomitant infrastructure funding, there is a much higher probability that the tribally-allocated spectrum would indeed be deployed in services generating benefits for end users in a timely manner. Such arrangements also help to overcome incentives (much prevalent in Canada) for speculators to buy the lots with gains from future arbitrage and not service delivery as the primary motivation. US proposals for tribal spectrum ownership, together with funding, would imply positive gains from skills development and application deployment available. That would have been far more likely to engender human capital gains than the New Zealand arrangements in place.

## 5 Conclusion

The policy intentions of ensuring that telecommunications markets are both competitive and comprehensive, providing services to all communities, and especially those facing economic and social disadvantages, are honourable. However, we have shown in this paper via the literature and four case studies that using spectrum ownership as a means of addressing those policies is not straightforward. Spectrum set-asides to stimulate competitive entry can work (New Zealand in 1999-2000) but only if there is a genuine competitiveness problem to be addressed and no other distortions exist in the regulatory regime that discourage infrastructure investment in the small remote communities that are vulnerable to under-service. Direct subsidies (to either operators or, preferably, consumers) may be necessary.

Using spectrum ownership to address economic and/or social development amongst disadvantaged communities is unlikely to address the disadvantages in and of itself. Ownership (or a share of it) of the firms delivering telecommunications services, and those using telecommunications services for product and service delivery is a more direct way of doing this (South Africa). However, owning these firms requires access to capital to make investments in the complementary assets (both physical and human capital) if the gains are to ensue. This could be possible with additional funding dedicated to this purpose (e.g. the United States) but is likely to fail if the firms own spectrum but not the complements. Ongoing ownership is possible only if the flows of inward capital continue in the future (this was not sustainable in New Zealand in the mid 2000s and is unlikely to be so with the 2022 MOU arrangements).

The question of whether indigenous people have a right to own and control spectrum separate and distinct from the state management authority is fraught. If the territories are geographically distinct, then this may be feasible (US tribal territories) but not if the spectrum competes with other commercial service offerings (NZ). There are potentially legitimate reasons why such ownership may satisfy cultural autonomy under the UNDRIP, but subdivision will inevitably have some economic consequences which the tribal owners must be aware of - choosing not to use spectrum for cultural reasons will deprive the users of efficient telecommunications services. If the affected consumers are confined to the tribal communities themselves (e.g. the US), then this is their choice to make. But when the economic consequences spill over into the telecommunications markets where all other consumers participate, then economic harms will occur relative to the counterfactual of no such set-asides occurring (NZ). The issue of giving indigenous people a privileged position in government spectrum policy formulation does not appear to be constitutionally supportable in a democratic country, due to the lack of accountability of the indigenous manager to the general population.

---

<sup>6</sup><https://www.icasa.org.za/uploads/files/The-State-of-the-ICT-Sector-Report-31-March-2024.pdf>

For this reason alone, many questions remain about the legitimacy of the New Zealand MOU arrangements, which the authors would caution other jurisdictions against adopting.<sup>7</sup>.

## References

- Blackwater, Darrah. 2023. "FCC Owes Tribes Billions for Tribal Spectrum Sales." *ICT News*. <https://ictnews.org/opinion/fcc-owes-tribes-billions-for-tribal-spectrum-sales>.
- Blackwater, Darrah, Iliia Murtazashvili, and Martin B. H. Weiss. 2023. "Spectrum Sovereignty on Tribal Lands: Assessing the Digital Reservations Act." *Journal of Information Policy* 13: 221–48.
- Blackwater, Darrah, Iliia Murtazashvili, and Martin BH Weiss. 2024. "Polycentric Systems for Spectrum Management: The Case of Indigenous and Tribal Spectrum Sovereignty." *European Journal of Law and Economics*, 1–27.
- Cambini, Carlo, and Nicola Garelli. 2017. "Spectrum fees and market performance: A quantitative analysis." *Telecommunications Policy* 41 (5): 355–66. <https://ideas.repec.org/a/eee/telpol/v41y2017i5p355-366.html>.
- Cameron, Aidan. 2013. "Maori Rights in the 4G Radio Spectrum: Fantasy or the Future of Treaty Claims." *Otago Law Review* 13: 181.
- Cave, Martin, and Rob Nicholls. 2017. "The Use of Spectrum Auctions to Attain Multiple Objectives: Policy Implications." *Telecommunications Policy* 41 (5-6): 367–78.
- Cave, Martin, and Tommaso Valletti. 2000. "Are Spectrum Auctions Ruining Our Grandchildren's Future?" *Info* 2 (4): 347–50.
- Cocullo, Jenna. 2022. "Spectrum Unceded: How Indigenous People Are Fighting for Digital Sovereignty in a Wireless World." *The Wire Report*. <https://www.thewirereport.ca/2022/09/30/spectrum-unceded-how-indigenous-people-are-fighting-for-digital-sovereignty-in-a-wireless-world>.
- Connolly, Michelle, Nelson Sá, Azeem Zaman, Christopher Roark, and Akshaya Trivedi. 2018. "The Evolution of US Spectrum Values over Time." *Economic Research Initiatives at Duke (ERID) Working Paper*, no. 247.
- Cramton, Peter, Allan T. Ingraham, and Hal J. Singer. n.d. "The Effect of Incumbent Bidding in Set-Aside Auctions: An Analysis of Prices in the Closed and Open Segments of FCC Auction 35." *Telecommunications Policy* 32 (3-4): 273–90.
- Cramton, Peter, Evan Kwerel, Gregory Rosston, and Andrzej Skrzypacz. 2011. "Using Spectrum Auctions to Enhance Competition in Wireless Services." *Journal of Law and Economics* 54 (S4): S167–88.
- Crandall, Robert, and Alan Ingraham. 2007. "The Adverse Economic Effects of Spectrum Set-Asides." *Canadian Journal of Law and Technology* 6 (3): 131–40.
- Dippon, Christian. n.d. "An Accurate Price Comparison of Communications Services in Canada and Select Foreign Jurisdictions." *Social Sciences Research Network*, no. 3309214. [https://papers.ssrn.com/sol3/papers.cfm?abstract\\_id=3309214](https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3309214).
- El-Moghazi, Mohamed, and Jason Whalley. 2021. "Towards a Future-Proof International Spectrum Policy?" In *The Debates Shaping Spectrum Policy*, 47–84. CRC Press.
- Fellows, G Kent, and Jeffrey Church. 2023. "Efficient Policy to Promote the Interests of Wireless Consumers: Lessons from Misallocating Spectrum to Promote Competition in Canada." *Available at SSRN 4568449*.
- Global System for Mobile Association. 2017. "Introducing Spectrum Management." Report. London: Global System for Mobile Association. <https://www.gsma.com/spectrum/wp-content/uploads/2017/04/Introducing-Spectrum-Management.pdf>.
- Guiffard, Jean-Baptiste, Marc Ivaldi, Julienne Liang, and Louise Aimene. 2023. "Welfare Cost of Mobile Spectrum (Mis) Allocation." *Available at SSRN 4415303*.
- Hazlett, Thomas W, and Roberto E Munoz. 2009. "Spectrum Allocation in Latin America: An Economic Analysis." *Information Economics and Policy* 21 (4): 261–78.

---

<sup>7</sup>For a more focused examination of the legal and constitutional issues raised by the NZ MOU, see B. Howell (2024)

- Hoppe, Heidrun C., Philippe Jehiel, and Benny Moldovanu. 2006. "License Auctions and Market Structure." *Journal of Economics & Management Strategy* 15 (2): 371–96. <https://doi.org/https://doi.org/10.1111/j.1530-9134.2006.00104.x>.
- Horrigan, John. 2024. "The Affordable Connectivity Program Creates Benefits That Far Outweigh the Program's Costs." Report. Wilmette, Illinois: Benton Institute for Broadband; Society. [https://www.benton.org/sites/default/files/ACP-Cost-Benefit\\_0.pdf](https://www.benton.org/sites/default/files/ACP-Cost-Benefit_0.pdf).
- Howell, Bronwyn. 2024. "One Government, Two Systems, Zero Consistency? New Zealand's Confused Approach to Radio Spectrum Rights Allocation and Management." *SSRN*. to be confirmed.
- . n.d. "Testimony to the Canadian Standing Senate Committee on Transport and Communications Bill s-242, an Act to Amend the Radiocommunication Act." <https://sencanada.ca/en/Content/Sen/Committee/441/TRCM/45EV-56036-E>.
- Howell, Bronwyn E, and Petrus H Potgieter. 2022. "Effective Competition and Ineffective Mobile Industry Regulation in South Africa." *Telecommunications Policy* 46 (7): 102317.
- Howell, Bronwyn, and Xin Tang. 2023. "Using Spectrum Allocations to Address Indigenous Rights Claims: The Case of New Zealand." *Telecommunications Policy* 47 (10): 102642. <https://doi.org/https://doi.org/10.1016/j.telpol.2023.102642>.
- International Telecommunications Union. 2015. "Measuring the Information Society Report 2015." Report. Geneva: International Telecommunications Union. <https://www.itu.int/en/ITU-D/Statistics/Documents/publications/misr2015/MISR2015-ES-E.pdf>.
- Jamison, Mark. 2024. "Broadband Pricing Under the Broadband Equity, Access, and Deployment Program."
- Koutroumpis, Pantelis, and Martin Cave. 2018. "Auction Design and Auction Outcomes." *Journal of Regulatory Economics* 53 (3): 275–97. [https://EconPapers.repec.org/RePEc:kap:regeco:v:53:y:2018:i:3:d:10.1007\\_s11149-018-9358-x](https://EconPapers.repec.org/RePEc:kap:regeco:v:53:y:2018:i:3:d:10.1007_s11149-018-9358-x).
- Lewis, Charley. 2020. "The Universal Service Fund." In *Regulating Telecommunications in South Africa: Universal Access and Service*, 171–216. Cham: Springer International Publishing. [https://doi.org/10.1007/978-3-030-43527-1\\_5](https://doi.org/10.1007/978-3-030-43527-1_5).
- Lewis, Charley, and Charley Lewis. 2020. "UAS Policy: From Conception to Outcomes." *Regulating Telecommunications in South Africa: Universal Access and Service*, 299–333.
- Miah, Mohammad Dulal, Yasushi Suzuki, Mohammad Dulal Miah, and Yasushi Suzuki. 2018. "Non-Market Allocation and Rent Seeking." *Power, Property Rights, and Economic Development: The Case of Bangladesh*, 109–30.
- Ministry of Business, Innovation and Employment. n.d. "Radiocommunications History in New Zealand." Report. Wellington: New Zealand Government. <https://www.rsm.govt.nz/assets/Uploads/documents/384b04ec58/radiocommunications-history-in-new-zealand.pdf>.
- Neethling, Claudine. 2009. "Pricing Radio Frequency Spectrum in South Africa." *Journal of Advances in Management Research* 6 (2): 172–87.
- Pogorel, Gerard. 2007. "Nine Regimes of Radio Spectrum Management: A 4-Step Decision Guide." *Communications & Strategies*, no. 65: 169.
- Song, Steve. 2020. "Spectrum Policy Across Africa." *Frequencies: International Spectrum Policy*, 68.
- Southwood, Russell. 2022. "Africa 2.0: Inside a Continent's Communications Revolution." *Africa 2.0*, 1–302.
- Telus. 2023. "Reforming Canadian Spectrum Policy for 5G and Beyond." Report. Ottawa: Telus. [https://assets.ctfassets.net/fltupc9ltp8m/1oe0oJ7TyUkHgwLXLihr0X/3c4da2b9bf4fd7794500cc4f3f5cc153/22-1343\\_Spectrum\\_White\\_Paper\\_Full\\_Final.pdf](https://assets.ctfassets.net/fltupc9ltp8m/1oe0oJ7TyUkHgwLXLihr0X/3c4da2b9bf4fd7794500cc4f3f5cc153/22-1343_Spectrum_White_Paper_Full_Final.pdf).
- Woroch, Glenn A. 2020. "Spectrum Concentration and Performance of the US Wireless Industry." *Review of Industrial Organization* 56 (1): 73–105.