The Impact of Obligations in Spectrum Value

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Abstract[*]

Radiofrequency spectrum is an essential asset for mobile network operators. Governments set its value to organize competitive frequency auctions and define recurrent payments, such as taxes and right of use. This publication sustains that governments should value radio frequency spectrum as a function of the intended frequency use policy and corresponding obligations. A mathematical formula is proposed to articulate, quantitatively, the relationship between spectrum value and regulatory obligations, including promoting new market entrants, conditioning of wholesale obligations, definition of coverage goals, and requirement to support public safety and first respondent services. This paper targets, in general, the telecommunication ministries, national regulatory authorities, and government entities that address the topic of valuing radio frequency spectrum.

JEL Codes: C2, Q3, O38
Keywords: adaptation, auctions, broadband, coverage, frequency, innovation policy, innovation, innovation subsidies, mobile, patent policy, public research grants, public safety, radiofrequency, research, research and development policy, research subsidies, sci tech, scientific, spectrum, technical, technology, technology policy, telecommunications, wholesale, wireless

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1. Introduction

The radio frequency spectrum is a twenty-first century commodity, relating to the international mobile telecommunications (spectrum) that are essential for wireless broadband communication (wireless)[1]. Most people and various devices are, and will continue to be, wirelessly connected to the internet. Spectrum is the raw material that enables wireless networking. Mobile network operators (MNO) design, finance, deploy, operate, and maintain wireless networks that provide coverage and connectivity to users and devices. In turn, MNO networks enable the services and applications that are supplied by internet and content service providers and application developers to generate an increasing amount of data.[2] These services and applications enable economic growth and social development in the modern world.[3]

Until now—unlike other commodities such as oil—there is not yet a substitute for spectrum. The quantity of spectrum is limited by the laws of physics and the slow pace of international and national efforts to identify and make it available for mobile broadband usage. With quantity not keeping up with[4] demand, it is envisaged that the value of spectrum will continue to increase in the foreseeable future.

Unlike other infrastructures, the wireless network infrastructure is capital-intensive, requiring MNOs to invest annually to expand its coverage map, increase the capacity for traffic handling, progress at the same rate as technological innovation, remain competitive, and avoid functional obsolescence. As MNO revenues flatten and investments increase, the return on capital employed (ROCE) for wireless network infrastructure has approached the weighted average of cost of capital (WACC[5]) to similar levels of other commodity industries.[6] An increase

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[1] Wireless refers to mobile broadband or what the ITU Radiocommunication Sector (ITU-R) designates as land mobile and fixed services (see http://www.itu.int/en/ITU-R/Documents/ITU-R-FAQ-IMT.pdf).
[2] Alphabet (Google's parent company), Amazon, Apple, Facebook, and Microsoft collectively made over US$25 billion in net profit in the first quarter of 2017 (see http://www.economist.com/news/leaders/21721656-data-economy-demands-new-approach-antitrust-rules-worlds-most-valuable-resource).
[3] In Latin America and the Caribbean, a 10 percent higher broadband penetration on average is associated with 3.19 percent higher GDP, 2.61 percent increased productivity, and 67,016 new jobs (see https://publications.iadb.org/handle/11319/5754).
[4] The ITU, in its Report ITU-R M.2290-0 (Future Spectrum Requirements Estimate for Terrestrial IMT, December 2013) estimated a total spectrum requirement of between 1,340 megahertz (MHz) and 1,960MHz by 2020 (https://www.itu.int/dms_pub/itu-r/opb/rep/R-REP-M.2290-2014-PDF-E.pdf). Ofcom, the UK Regulator, has licensed 741MHz of spectrum, which is or could be used for mobile and plans to make available 446MHz below millimeter wave frequencies (mmWave), totalizing 1,187MHz. In addition, Ofcom (https://www.ofcom.org.uk/__data/assets/pdf_file/0033/79584/update-strategy-mobile-spectrum.pdf) estimates mmWave frequencies to provide around 1 to 5 GHz of additional bandwidth. Is worth to notice that mmWave are interesting to render capacity and not to provide coverage.
[5] WACC represents the firm's blended cost of funds or the minimum return (or "hurdle rate") that it must achieve in order to satisfy its investors' (shareholders and debtholders) expectations. https://en.wikipedia.org/wiki/Weighted_average_cost_of_capital.
[6] Data for 2010 suggest that operators generated profits at a modest level, as they did in 2007 and 2008, with ROCE at 13 percent (see http://www.gsma.com/publicpolicy/wp-content/uploads/2012/09/Europe-Observatory-2010.pdf).

in the value of spectrum represents a financial burden for operators in addition to the investments they require to build, operate, and upgrade wireless networks.[7] It is no wonder that MNOs are attempting to climb the value chain and benefit from the wealth that the applications and entertainment sectors provide, exemplified by the recent acquisition of Time Warner by AT&T.[8]

The aim of this paper is not to cover the direction in which the industry structure is heading, nor the government policies required for wireless. Rather, it proposes that the value of spectrum to MNOs is inversely proportional to the cost of the wireless network that is required to fulfill license obligations. While sovereign governments are free to set their own priorities and define the mechanisms necessary to achieve their objectives, spectrum-wise, this paper focuses on a specific theory that may benefit governments when defining their spectrum policy, assignment mechanism, and license obligations.

The more demanding the license obligations, the higher the cost of the wireless network for MNOs, and the spectrum value set by governments should reflect this to ensure the financial viability of MNO wireless network projects. Furthermore, focus should be placed on the spectrum valuation of so-called coverage bands below 1 GHz, specifically digital dividend frequency bands. These bands combine excellent propagation characteristics and sizeable bandwidth, making them essential for wireless networks to provide mobile broadband.[9],

2. Definitions

2.1 Number of Cell Sites

It is customary to define the cost of cellular networks as a function of the number of cell sites required to achieve certain design objectives. Although there are many different types of cellular sites and there are other network domains and costs to consider in addition to radio access networks, such as transport and control network domains, information technology (IT) platforms, and professional services, the assumption is that it is a good approximation to apply the number of sites as the driver of network cost. Every country differs, with some having more existing sites

[7] Average final prices paid in auctions were found to have risen 250 percent from 2008 to 2016, with the most exorbitant price tags often influenced by policy decisions (see http://www.businesswire.com/news/home/20170222005053/en/GSMA-Report-Shows-High-Spectrum-Prices-Threaten).

[8] See http://about.att.com/story/att_to_acquire_time_warner.html.

[9] Bands from the first digital dividend in Region 2 (800MHz), Regions 1 and 3 (700MHz) and the second digital dividend (700MHz in Region 2 and 600MHz in Regions 1 and 3) (see https://www.ericsson.com/res/docs/2013/ericsson-apt700-creating-a-truly-global-band.pdf).

than others that can or cannot be used to install a new radio frequency amplifier. This also applies to other network domains, where there may or may not be backhaul connectivity, backbone network capacity, data centers, and managed service centers available. Despite the fact that not all countries will have the same level of telecom infrastructure, the number of cellular sites as the main cost driver of wireless networks can be applied. Furthermore, it is a common and well-accepted practice that is well understood in the Industry.

2.2 Radio Network Planning

These are engineering projects undertaken with Radio Network Planning tools.[10] The tools are able to determine the number of sites required to achieve a design objective, expressed in coverage mapping, service quality, and quality of experience parameters.

2.3 Existing Population Coverage

Most countries have achieved national mobile telephony service coverage, usually using frequency bands below 1 GHz of central frequency[11], which are implemented through macro base stations, deployed by MNOs to cover major localities, roads, and sites of interest. The existing population coverage of mobile telephony with less than 1 GHz frequency bands is what is referred to in this discussion paper as the existing population coverage (EPC(%)), which implies a percentage of the population with access to mobile telephony, which is usually reported by national regulatory authorities (NRA) and compiled by various international organizations.[12] This paper assumes that governments have conducted radio network planning exercises to determine (i) how many cellular sites are needed to achieve the EPC(%) with the licensed digital dividend band and (ii) how many cellular sites are required to achieve the coverage, services, and quality required by national broadband policy objectives, in order to compare them. The increase in cost between what already is in place and what is required should be reflected in the reduction of the spectrum value for the MNO, as obligations apply.

2.4 Additional Base Stations Factor

If $N_{EPC(\%)}$ is the total number of sites to achieve the $EPC(\%)$ using the targeted digital dividend band, as determined by radio network planning studies, then the additional base stations factor

[10] Examples are Forsk Atoll, Planet, Opera, and CellPlan, among others.
[11] Eight hundred and fifty MHz or 900MHz.
[12] GSMA, Organisation for Economic Co-operation and Development (OECD), ITU Telecommunications Development Sector, the World Bank, and such international consultants as Pyramid Research, among others.

(F_{RB}) is the percentage of increment with respect to the $N_{EPC(\%)}$ that is necessary to achieve the proposed government broadband policy goals. If the number of sites necessary to achieve the broadband policy goal is N_{BB_Policy} then:

$$N_{BB\_Policy} = N_{EPC(\%)}(1 + F_{RB})$$

2.5 Reference Value of the Spectrum

The reference value of the spectrum (VS_{I_MNO}) is the price that the incumbent MNO—specifically the dominant one—would pay for the digital dividend band to be auctioned. In this paper, the reference value is

$$VS_{I\_MNO} = 1$$

This VS_{I_MNO} is expressed as U.S. dollars/MHz/Pop[13] in this paper.

2.6 Existing and New Sites

To reach $EPC(\%)$, radio network planning requires a number of cellular sites $N_{EPC(\%)}$. This $N_{EPC(\%)}$ will be composed of existing (reusable) sites $N_{\exists}$ and new sites $N_{\nexists}$:

$$N_{EPC(\%)} = N_{\exists} + N_{\nexists}\ , F\exists = \frac{N_{\exists}}{N_{EPC(\%)}}\ , F\nexists = \frac{N_{\nexists}}{N_{EPC(\%)}}\ , F\exists + F\nexists = 1$$

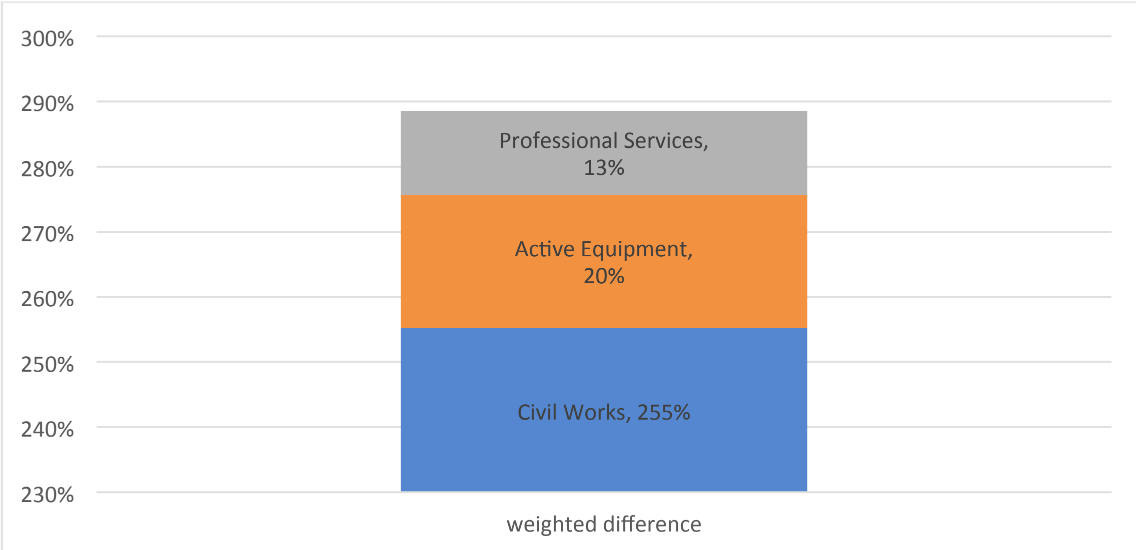
Factors $F\exists$ and $F\nexists$ represent the proportion of existing and new sites required to achieve $N_{EPC(\%)}$ using the targeted digital dividend band and applying the desired government policies and obligations, as reported by network planning exercises. For simplification, it is assumed that the number of reusable sites $N_{\exists}$ remains a constant estimate until the final network design is achieved, despite the potential that it will vary due to conditions, such as permits and backhaul availability. This incertitude, however, is offset by the difference in cost between existing and new sites, which can be significant.

2.7 New to Existing Cost Ratio

Based on experience, the cost of a new site is more expensive than deploying an existing site—up to three times more so (F_{CN}). This is in spite of the varying practices and price levels in different countries.

[13] Normalized purchasing parity in U.S. dollars per MHz per inhabitant is a common measure for the value of spectrum.

Figure 1. Relative Cost Difference of a New versus an Existing Site



If C_{CN} is the average cost of a new cell site and C_{CE} is the average cost of sharing an existing cell site, then

$$F_{CN} = C_{CN}/C_{CE} \sim 3 \text{ , } F_{CN} \in (2.88{,}3.12)$$

2.8 The New Entrant Factor

In most markets, three MNOs will attract business, which requires certain incentives. A study by DotEcon & Aethna for Ofcom[14] shows that the reserve prices and actual results of frequency auctions for the first digital dividend in ITU-R Region 2 (the 800MHz band), a newcomer will pay less than the incumbent MNO(s) for the same bandwidth in this spectrum band. We define the New Entrant Factor *(F_{NE})* as how much less a new market entrant would pay for the same amount of spectrum in the targeted digital dividend band, as follows:

$$\frac{Value\_of\_Spectrum\_New\_Entrant}{VS_{I\_MNO}} = \frac{VS_{NE}}{VS_{I\_MNO}} = F_{NE}\text{ , }F_{NE} \in (0.55{,}0.60)$$

This fact reflects the challenge of attracting new MNOs in a mature market and it illustrates the need to reduce the reserve price for competitive frequency auctions to attract a new comer entry.[15] While increasing the number of MNOs from three to four is advantageous, it is

[14] *Spectrum value of 800MHz, 1800MHz and 2.6GHz: A DotEcon and Aetha Report for Ofcom* (DotEcon, July 2012).
[15] While this is not the only incentive, there are many such as spectrum caps, fiscal incentives, and guaranteed revenues. In the report referred to, however, it is clear that a newcomer will pay less for the same frequency when

nevertheless a challenge for NRAs, policy makers, and governments to attract new market entrants. It calls for incentives that will encourage newcomers to come into the country, invest and compete against stablished MNOs. The number of vertically integrated MNOs acting in an specific country market is finite, especially in today's wireless industry infrastructure. Collaboration among the four MNOs to share network assets will lower costs, potentially yielding to market consolidation.[16] While increasing the number of MNOs in a country market may increase retail competition, governments and NRAs should also consider incentivizing and even mandating wireless wholesale serviced offers, to achieve more competition in the retail market.[17]

2.9 The Wholesale Factor

Many regulators intend to increase competition. Offering wholesale services provides an incentive to increase such competition and mitigate market concentration.[18] In a Bell Labs study[19] on the contribution of wholesale services in the end-to-end ROCE, based on public market data from the United Kingdom telecom market, the wholesale factor (F_{FW}) was found to depend partially on the end-user revenue—split between wholesaler and retailer, and varying between 27 percent and 64 percent of the end-user price, depending mostly on the spectrum discount to be applied, which is necessary to enable the financial viability of the retailer's business, whose margins range between 30 percent to 60 percent of the end user price.

$$\frac{Value\ of\ Spectrum_{Full\ \text{wholesale}}}{VS_{I\_MNO}} = \frac{VS_{FW}}{VS_{I\_MNO}} = F_{FW}, F_{FW} \in (0.30, 0.60)$$

In practical terms, a governmental obligation to wholesale implies a spectrum discount of approximately one half of the reference spectrum value. The rationale is that MNOs will pay less for spectrum that has to be shared with other licensees (i.e., other MNOs or MVNOs).

evaluating a consolidated market, given the increased risk of competition and lack of access to its own infrastructure.

[16] See the case of France, where it has increased three to four in network sharing. In Mexico, market consolidation has reduced the number of operators from four to three.

[17] See "Open Access with a Mobile Wholesale NetCo" https://www.detecon.com/en/Publications/open-access-mobile-wholesale-netco.

[18] See *OECD Review of Telecommunication Policy and Regulation in Mexico* https://www.oecd.org/sti/broadband/50550219.pdf.

[19] Bell Labs study by Fani Kontothanasi, *Retail versus Wholesale: Return On Capital Employed (Roce)*. Available on demand from Bell Labs. Contact mark.bass@bell-labs.com and the author of this paper.

3. Coverage Obligations and Existing Infrastructure Factors

In most countries, the population coverage of mobile telephony determines the coverage map of existing wireless infrastructure, typically in the range of 90 percent of population.[20] Below this $EPC(\%)$, there is an underlying infrastructure that can be leveraged to a greater or lesser extent, thus providing economies in the deployment of the network. Conversely, beyond $EPC(\%)$, it is less probable that there is any existing infrastructure to leverage, thus increasing the relative cost of deployment wireless broadband coverage in those areas. By deploying a new wireless network, using a digital dividend frequency band, the effect of sharing existing cell sites and building new ones will be represented by F∃ and F∄ and by F_{CN}, as follows:

$$\frac{VS'}{VS} = \frac{(1 - F_{RB})}{(F\exists + F\nexists F_{CN})} + \frac{F_{RB}}{F_{CN}}$$

Where VS' is the value of spectrum corresponding to coverage obligations to achieve $EPC(\%), F_{RB}$ is the percentage of additional coverage sites necessary to fulfill coverage obligations beyond N_{EPC}. F∃ and F∄ are the proportion of existing and new sites necessary to achieve the $EPC(\%)$, and F_{CN} is the factor that represents how many times more expensive a new cellular site may be when compared to an existing site in terms of investment. If $F_{RB} = 0$, it would imply that the broadband policy goal would be lower or equal to $EPC(\%)$, thus eliminating the second term on the equation and leaving only the first. In the latter case, the value of spectrum still could be reduced, depending on the proportion of new cell sites versus existing ones to achieve the number of sites. The more new cellular sites to be deployed, the lower the value should be of spectrum, thus incentivizing new infrastructure investment. In the case that both $F_{RB} = 0$ and $F\nexists = 0$ then $F\exists = 1$ and $\frac{VS\prime}{VS} = 1$. Figure 2 shows the increase in cost due to this effect.

[20] The penetration of mobile telephony is more or less above this figure in almost all the world. According to World Bank data (http://databank.worldbank.org), 66 percent of the world's population lives in countries with more than 90 percent mobile telephony penetration.

Figure 2. Relative Cost of a New Network WRT. An Example

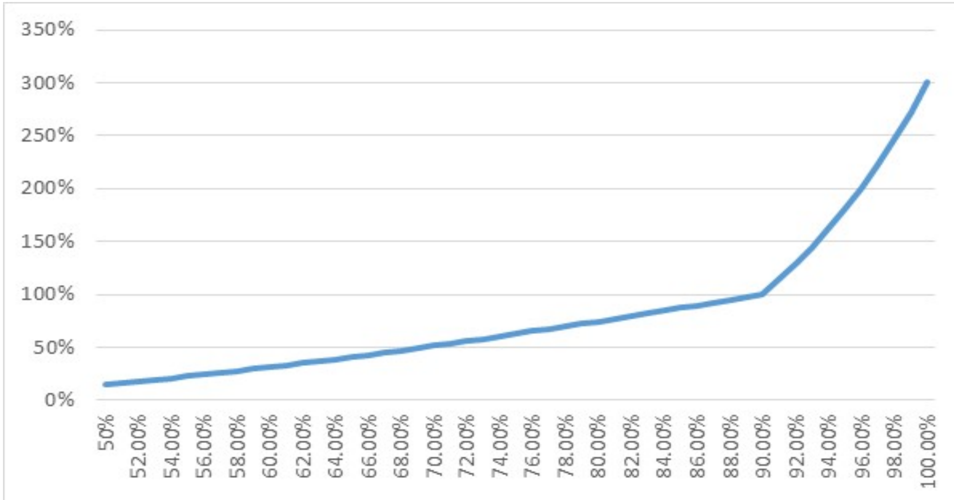


Figure 2 shows a linear increase of cost as a function of population coverage up to a certain population coverage goal. In the graph it is assumed that the percentage of population covered by existing mobile telephony services in the targeted market is $EPC(\%) = 90\%$. Beyond 90% of population coverage the additional number of sites and the higher unit cost of them increase the investment that is essential to cover areas that could be of lower commercial interest, thus challenging the financials of a developer. This effect should be part of the spectrum valuation if coverage obligations apply.

4. Public Safety Obligations

Public safety is an increasingly important issue for 4G wireless networks and specifically those using LTE communications standard for mobile wireless broadband communications. The excellent propagation characteristics of digital dividend bands ensure they can provide the coverage required by public safety services. The use of Band 14 in the United States of America for Public Safety mobile broadband services also encourages the use of 700 MHz bands for public safety purposes.[21] In the event that governments wish to impose public safety obligations on the targeted digital dividend auction, the spectrum valuation should be affected accordingly. Although an LTE network can support both public safety and commercial services in the same network, operating simultaneously by using quality of service, preemption, and priority[22] (QPP),

[21] In the United States, Firstnet uses Band 14, a 2x10MHz piece of the 700MHz Digital Dividend Band https://www.firstnet.gov/tags/band-14.

[22] Available as the evolution of LTE per Release 13.

the coverage, services, and availability requirements of both types of users will differ significantly.

Public safety coverage could include the coverage of unpopulated national borders, isolated roads, and national parks that are prone to wildfires, volcanic eruptions, hurricanes, earthquakes, tsunamis, and other natural disasters. It could cover distant military installations, isolated communities in need of social inclusion, special economic areas, and areas subject to national emergencies or contingencies that may or may not be planned. Additional services and functionalities include compatibility and interoperability with other public safety services, such as land mobile radio (LMR) networks, or the implementation of mission-critical features as direct-mode and group-call functionalities, plus the interoperability with push-to-talk (PTT) standards, such as Project 25 (P25) or Tetra technology[23]. For increase service availability for Public Safety usage, there are a multitude of options, from rugged terminal equipment to hardened base stations, including enhanced electric power autonomy, redundant backhaul transmission links, and other resilience or security measures in the various network domains[24]. Let us define factor F_{PS} as inversely proportional to the increase in network infrastructure cost to support Public Safety services, features and availability required by the government, applied to the territory considered in the F_{RB} factor:

$$F_{PS} \propto \frac{C_{CO}}{C_{PS}}, \; C_{PS} \geq 1$$

Where C_{CO} and C_{PS} represent the average cost of a commercial cell site and a Public Safety compatible cell site, respectively, F_{PS} represents the proportional decrease in spectrum valuation with respect to the increase in public safety requirements in terms of services, functionalities, and availability of the network infrastructure[25]. For example, if $C_{PS} = 2C_{CO}$, then $F_{PS} = 50\%$, potentially impacting the value of spectrum VS by half. Conversely, if there are no public safety requirements in terms of functionality, services, or additional service availability, then, $C_{PS} = 1$ and $F_{PS} = 1$.

[23] Firstnet is an example of a convergent public safety and commercial use mobile broadband network (see https://www.firstnet.gov/).

[24] Wireless network domains are typically terminals, access, backhaul, backbone, core, operational support systems/business support systems, security, and applications.

[25] Terminals are not considered in F_{PS}, only the aggregated cost of network infrastructure required to fulfill specific requirements of public safety services, such as increase availability, additional security and the support of public safety specific network functionality such as LMR compatibility and the support of mission critical network features such as group-call or direct mode calling.

5. General Formula

The general formula for the relative value of spectrum as a function of obligations, such as a new market entrant, offering of wholesale services, increased coverage footprint, and public safety requirements, would look as follows:

$$\frac{VS'}{VS} = F_{PS}\, F_{NE}\, F_{FW}\{\frac{(1 - F_{RB})}{(F\exists + F\nexists F_{CN})} + \frac{F_{RB}}{F_{CN}}\}$$

Where $F_{PS} \in \{.5,1\}, F_{NE} \in (0.55,0.60), F_{FW} \in (0.3,0.6), F\exists + F\nexists = 1, F_{CN} \in (2.88,3.12)\ F_{RB} \in (0,1)$[26]

6. Results

Figure 3 illustrates the results of the proposed general formula. The value of spectrum is reduced at the time the existing population coverage $EPC(\%)$, in the example set to 90%, is reached. The pace of reduction of the spectrum value then accelerates due to the increase of new sites to go beyond the existing population coverage $EPC(\%)$—up to 100 percent. This reference scenario (designated as "coverage" in the figure) is then further affected by the other factors defined above, that is, the new entrant factor, the wholesale factor, and the public safety factor, illustrating their potential impact in the reduction of the spectrum value as obligations accumulate. Table 1 provides some samples based on Figure 3.

[26] Please note that F_{RB} represents the proportion of sites necessary to achieve the desired population or territorial policy goal above the existing mobile telephony coverage $EPC(\%)$. This means that FRB would be always a percentage, therefore representing a value between within 0 to 100%, even though the number of sites necessary to achieve the policy goal may be much greater than the number of sites necessary to cover $EPC(\%)$ using the targeted digital dividend band.

Figure 3. Relative Value of Digital Dividend Spectrum as a Function of Coverage and Other Obligations

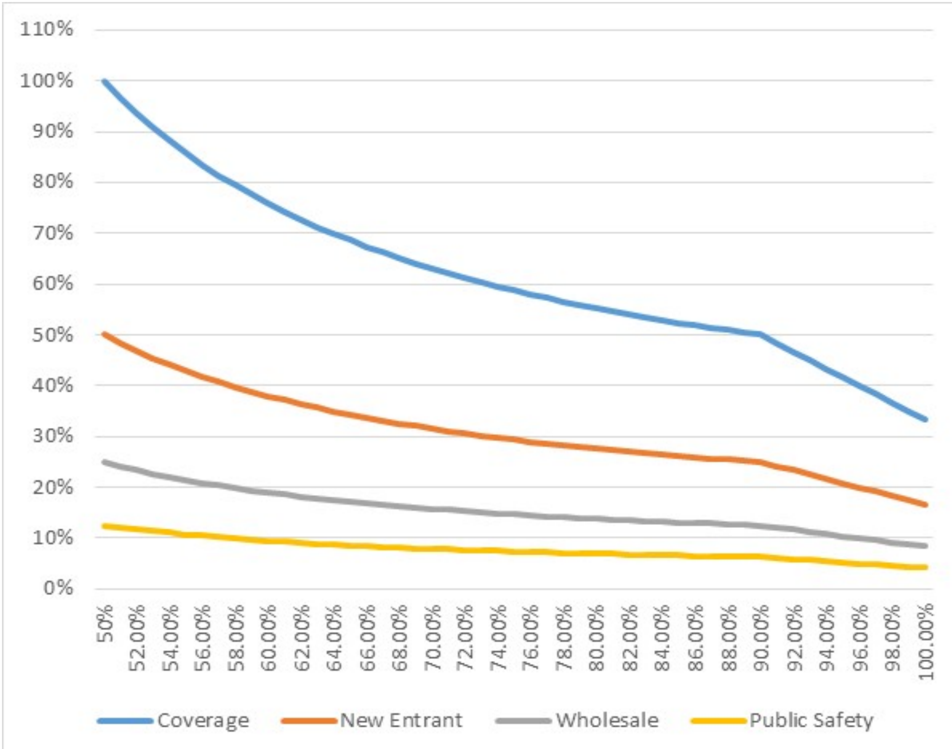


Table 1. Samples Based on Figure 3 (in percent)

Population coverage	Value of spectrum	New entrant impact	Wholesale impact	Public safety impact
50	100	50	25	13
90	50	25	13	6
95	42	21	10	5
98	37	18	9	5

The value of the spectrum in this example is reduced by 63 percent, down to 37 percent of the reference value (50 percent population coverage obligation by incumbent operator) to compensate additional investment so as to achieve 98 percent population coverage, assuming an existing population coverage $EPC(\,percent) = 90\,percent$. This 37 percent may be further impacted by additional obligations, such as a new entrant stimulus, wholesale services offering obligations, and public safety requirements, thus yielding to a spectrum value of 5 percent with respect to the reference value as all obligations accumulate.

7. Conclusions

The value of spectrum for MNOs, expressed in USD/MHz/Pop, should be a function of license obligations, notably coverage, new entrant stimulus, wholesale obligations, and public safety services support. The value of spectrum can be reduced by 82 percent, 91 percent, or 95 percent of the reference value in the case of a new entrant, or in the event wholesale offering and public safety usage obligations are applied. The value of the spectrum should be a function of government-defined obligations.[27]

8. Recommendations

Governments should perform radio network planning exercises periodically to understand the population coverage of the different bands by the MNOs in their national territory. They should also collect and map existing telecommunications infrastructure to promote the efficient use of existing infrastructure and incentivize investment in areas that are deficient in infrastructure. The value of the spectrum should be addressed regularly, although it should be affected with a predictable framework to increase certainty and predictability to the MNOs conducting their financial projections. Governments and investors now, in the twenty-first century, should understand in greater depth the quantitative aspects of telecommunications infrastructure, and assess them regularly and methodologically. They should also design smart incentives to promote projects that are conducive to the success of national broadband policies.

[27] See the case of Mexico's Red Compartida, whereby the value of the payment of rights was reduced significantly as a result of coverage, a new entrant, and full wholesale obligations (see http://www.cronica.com.mx/notas/2015/920719.html).