INFRASTRUCTURE

Assignment and use of radio spectrum – POLICY GUIDELINES AND ECONOMIC ASPECTS

Telecommunication Development Sector

Assignment and use of radio spectrum – policy guidelines and economic aspects

The present study on “Assignment and use of radio spectrum – policy guidelines and economic aspects” was prepared by Dr. Raúl Katz (Professor, Columbia Business School (Columbia University, USA) President, Telecom Advisory Services LLC) under the supervision of the ITU Telecommunication Development Bureau (BDT) in strong coordination with the ITU Radiocommunication Bureau (BR).

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Foreword

It is my pleasure to present this ITU report on policy guidelines and economic aspects of assignment and use of radio spectrum prepared by the Telecommunication Development Bureau (BDT) in coordination with the Radiocommunication Bureau (BR).

This report identifies guidelines on policy and economic aspects in relation to the assignment and use of the radio-frequency spectrum to allow national regulatory authorities, decision-makers and telecommunication/ICT service operators to make more efficient and optimal use of the spectrum. The objective of these guidelines is to extract the maximum benefit from the radio-frequency spectrum while maintaining the necessary balance with other key factors, such as coverage obligations, secondary market issues, and competition. In addition, this study provides an economic assessment of the impact of conditions and price in a frequency auction on the provision of traditional and digital services.

I trust that the findings of this report will serve as strategic guidance to assist ITU Members and all stakeholders in their discussions and decision making on the assignment and management of the radio-frequency spectrum and maximize technical and economic efficiency and social benefits.

Brahima Sanou

Director, ITU Telecommunication Development Bureau

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Introduction

The spectrum is a natural, non-renewable and scarce resource whose use therefore entails an opportunity cost[1]. Although it is often thought that spectrum scarcity might be less critical in some countries of Latin America, in many instances telecommunication operators are asking for more efficient spectrum assignment processes that would afford them more bandwidth to accommodate growing traffic needs. Moreover, national regulatory authorities (NRAs) responsible for managing the spectrum have to strike a balance between licensing and the costs thereof with other key factors such as associated coverage obligations (to help reduce the digital divide) and spectrum caps (to safeguard competition by avoiding spectrum monopolies). These different perspectives underline the need to manage the radio-frequency spectrum, so as to maximize technical efficiency, economic gains and social impact.

The radio-frequency spectrum is recognized worldwide to be a resource that requires strict management and control by States in order to achieve a nation's goals and objectives, while at the same time respecting national and international regulatory frameworks and paying attention to recommendations, procedures and arrangements emanating from international bodies such as the International Telecommunication Union (ITU), as well as complying with binding international agreements, conventions and treaties. In this context, and considering the growing demand for radio-frequency spectrum in the coming decades, the study and implementation of mechanisms to foster technical and economic efficiency in the use of the spectrum, thus increasing spectrum supply, and the dismantling of access barriers to promote dynamic market competition for the benefit of users, become a major strand of every country's telecommunication regulatory processes.

This study seeks to provide guidelines on policy and economic aspects in relation to assignment and use of the radio-frequency spectrum so as to place NRAs, decision-makers and telecommunication/ICT service operators in a position to make efficient and optimal use of the spectrum, endeavouring to extract maximum benefit from the spectrum in the short and long term while maintaining the necessary balance with other key factors (e.g. coverage obligations, secondary market, etc.). It also seeks to provide an economic assessment of the impact that the conditions and price in a frequency auction exert on the provision of services. Accordingly, this report comprises six chapters, as summarized below.

Chapter 1 defines the economic, technical and social principles that govern spectrum assignment and use. Building on this theoretical basis, Chapter 2 studies the different spectrum assignment models, describing the various types of auction, the functioning of secondary markets and the different sharing models. Chapter 3 follows on from this by examining the economic and market aspects to be considered in assigning and using the spectrum, focusing particularly on spectrum valuation methodologies. Chapter 4 investigates the economic aspects of the many principles of regulatory policy governing assignment and use of the spectrum: ever-growing demand and the digital dividend. In so doing, it presents a methodology to be used to estimate its economic value. Lastly, Chapter 5 puts forward guidelines that may be followed by NRAs to develop a technical capability to determine the economic value of spectrum.

[1] Opportunity cost or alternative cost is defined as the amount of the investment of available resources in an economic opportunity, at the expense of the best available alternative investment, or also as the value of the best alternative foregone.

1 Economic, technical and social principles governing assignment and use of the spectrum

1.1 Concept of radio-frequency spectrum

The radio-frequency spectrum is the portion of the electromagnetic spectrum (phenomenon by which electromagnetic waves are transmitted) that is used for telecommunications (radio, television, mobile telephony, radars, satellites, etc.). The radio-frequency spectrum has been set by convention as running from 8.3 kHz to 3 000 GHz, and is divided into frequency bands which are allocated to the various telecommunication services[2]. This allocation considers each band's specific characteristics in terms of signal propagation, which make it most suited for the provision of specific services (see Table 1).

Table 1. Uses and properties of bands in the radio-frequency spectrum

Band	Frequency range	Range	Common use	Bandwidth	Interference
VLF (myri-ametric waves)	3-30 kHz	1 000 km	Long-range radionavigation	Very narrow	Widespread
LF (kilo-metric waves)	30-300 kHz	1 000 km	Long-range radionavigation	Very narrow	Widespread
MF (hec-tometric waves)	300-3 000 kHz	2-3 000 km	Long-range radionavigation	Moderate	Widespread
HF (deca-metric waves)	3-30 MHz	Up to 1 000 km	Fixed point-to-point, Global broadcasting	Wide	Widespread
VHF (metric waves)	30-300 MHz	2-300 km	Broadcasting, Mobile, WAN	Very wide	Confined
UHF (deci-metric waves)	300-3 000 MHz	< 100 km	Broadcasting, Mobile, Satellite	Very wide	Confined
SHF (cen-timetric waves)	3-30 GHz	30-2 000 km	Fixed, Broad-casting, Mobile, WAN, Satellite communications	Very wide up to 1 GHz	Confined
EHF (mil-limetric waves)	30-300 GHz	20-2 000 km	Broadcasting, Fixed point-to-point, Mobile, Satellite com-munications	Very wide up to 10 GHz	Confined

Source: ITU 2011 ICT Regulation Toolkit. Radio Spectrum Management. Module 5, p. 12 (*www.ictregulationtoolkit.org/en/home*)

For example, the VHF (very high frequency) band accommodates terrestrial broadcasting (sound, television), radioamateur systems and maritime and aeronautical mobile services. The UHF (ultra-

[2] ITU Radio Regulations, Volume 1, Chapter 1: Terminology and technical characteristics. (The complete Radio Regulations are available at: http://www.itu.int/pub/R-REG-RR-2012).

high frequency) band accommodates terrestrial mobile networks, space radiolocation systems (such as GPS, GLONASS, etc.) and TV broadcasting transmitters.

In economic terms, the radio-frequency spectrum is an investment for the production of communications. As a resource, it is varied (since, as mentioned above, it comprises different categories or bands), it is scarce (cannot be recreated)[3], it cannot be stored (unlike other resources such as water or oil) and it can definitely be traded (bought and sold in terms of usage rights). These characteristics mean that spectrum access and use have to be managed. Table 2 provides a comparison of the spectrum with other natural resources.

Table 2. The spectrum as an economic resource

	Spectrum	Land	Oil reserves	Water
Is the resource varied?	Yes	Yes	Not very	Not very
Is it scarce?	Yes	Yes	Yes	Yes
Can it be made more productive?	Yes	Yes	Yes	No
Is it renewable?	Yes	Partially	No	Yes
Can it be stored for later use?	No	No	Yes	Yes
Can it be exported?	No	No	Yes	Yes
Can it be traded?	Yes	Yes	Yes	Yes

Source: ITU 2011 ICT Regulation Toolkit. Radio Spectrum Management. Module 5, p. 8. (*www.ictregulationtoolkit.org/en/home*)

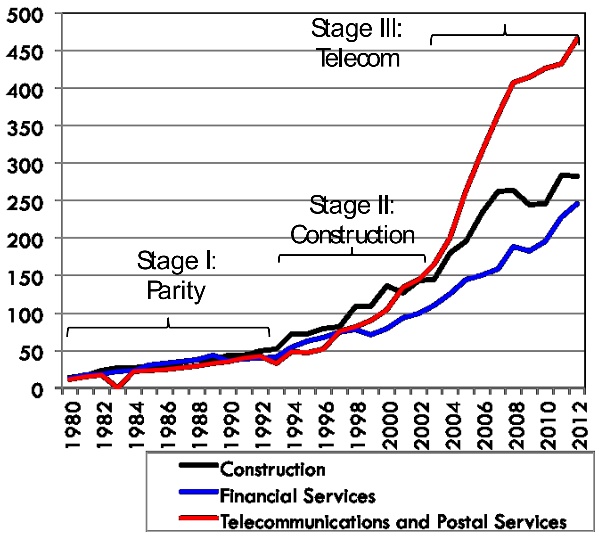
The spectrum can be exploited by dividing it into frequency bands (see Table 1), and by controlling its scope of action (by regulating transmitter power and antenna radiation patterns). Thus, before assigning spectrum to a user entity (such as a mobile telecommunication service operator or provider), the spectrum manager must set the frequency band, geographic coverage and maximum authorized radiated power.

1.2 Management of the radio-frequency spectrum

Radio spectrum management embodies a critical public policy decision because of the growing economic importance of telecommunications. The weight of telecommunications in the output of emerging nations is growing at an increasingly fast pace. For example, figure 1 presents the proportion of Senegal's GDP attributed to telecommunications.

[3] In the ITU-D document *Resolution 9 (Rev. Dubai, 2014): Participation of countries, particularly developing countries, in spectrum management*, contained in the Final Report of the World Telecommunication Development Conference (WTDC-14), p.210, it is considered "*that the continuing growth in demand for spectrum, from both existing and new radiocommunication applications, places ever greater requirements on a scarce resource*". Some of the items mentioned in that resolution to meet those requirements include, in particular, "*spectrum redeployment, licensing processes and best practices implemented in spectrum monitoring around the world, including consideration of new spectrum-sharing approaches*".

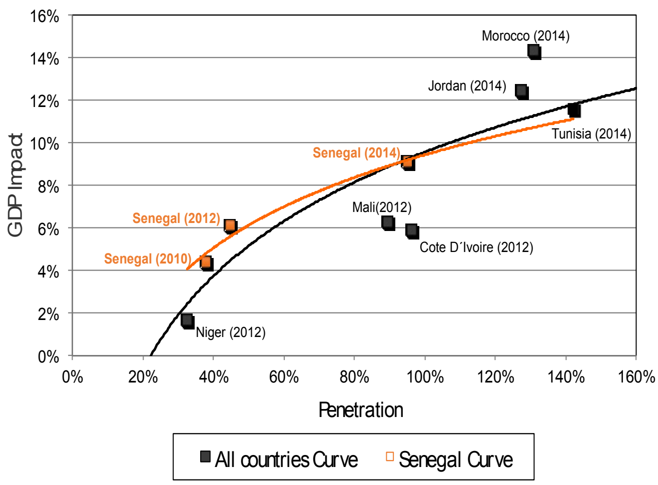
Figure 1: Senegal: GDP By Industry (1980-2012) (in CFA '000'000'000)



Source: Senegal National Accounts

As Figure 1 indicates, in the case of an emerging country like Senegal, beginning around the year 2002, the telecommunications industry started having a disproportionate weight in the country's GDP, when compared to other sectors such as construction and financial services. Furthermore, beyond its direct impact, telecommunications contribute indirectly to the growth of the economy as a whole (see Figure 2).

Figure 2: Africa: Mobile Telecommunications Economic Impact Vs. Wireless Penetration



Source: Katz and Callorda (2015)

Figure 2 presents the contribution of wireless telecommunications to GDP growth for several African countries. Each data point represents the coefficient of impact on GDP growth estimated through structural models in relation to wireless penetration. The slope of the curves indicates that the impact of wireless telecommunications on GDP growth tends to increase with penetration: an effect described as return to scale. In other words, not only are telecommunications increasingly important in terms of their share of GDP; their indirect contribution (or spill-over effects) are also increasing with penetration. In consequence, since spectrum is a critical input to the development of the industry, decisions on spectrum management carry considerable weight in terms of economic development.

In this context, if governments delay making decisions with regards to allocating spectrum to support the growth of telecommunications, they could create a bottleneck on future industry growth. Table 3 presents the growth in mobile telecommunications and mobile broadband connections for the African continent.

Table 3. Africa: Mobile Telecommunications Installed Base (in '000'000)

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Connections	543	638	739	815	901	987	1,068	1,136	1,196	1,249	1,287
Unique Subscribers	290	335	379	424	467	509	545	577	607	633	658
Mobile broadband (*)	17	32	52	78	108	141	181	224	271	318	364

Source: GSMA

This growth requires the allocation of spectrum to the wireless operators so they can deliver service with appropriate quality standards. However, the comparison of the amount of spectrum allocated to the wireless industry in Africa compared to the situation of industrialized countries the lag is self-evident (see Table 4).

Table 4. Spectrum Assigned To IMT Mobile Services (in MHz)

	United States	European Union	Ghana	Kenya	Nigeria	Senegal	South Africa	Tanzania
Assigned Spectrum	547	590	330	220	363	232	340	360
Un-assigned spectrum	---	---	30	130	---	128	20	---
Future blocks	500	500	250	250	250	250	250	250
Total	1,047	1,090	610	600	613	610	610	610

Sources: Plum Consulting; NRAs; operators

As Table 4 indicates, while the United States and the European Union have assigned in excess of 1,000 MHz to mobile telephony, several African countries do not exceed 610 even considering future blocks.

Insofar as the radio-frequency spectrum is a scarce national resource, like water, it is the property of the State (i.e. all citizens) and needs to be managed by the State's government[4] (a responsibility generally assumed by the executive authority and/or telecommunication regulator, although in some countries such as France, Tunisia and Colombia[5] there is a specific regulatory body).

[4] See ITU-D, Study Group 2, fifth study period (2010-2014), *Report on Resolution 9 (Rev. Hyderabad, 2010): Participation of countries, particularly developing countries, in spectrum management, which states in its §1.1 that "The radio-frequency spectrum constitutes the raw material of any radiocommunication system, and is an intangible asset linked to the sovereignty of each Member State and the exercise of regal powers".*

[5] National Spectrum Agency (NSA)

Spectrum scarcity is not an absolute value, since: "*The cause of its scarcity is to be found not only in institutional mechanisms, but also in a growing demand for uses resulting from technical progress. This demand comes up against the fact that there is an increasingly narrow bottleneck in the availability of the resource as well as in the allocation and access mechanisms*".[6]

The same source identifies the following key factors that contribute to the scarcity of frequencies and increased spectrum access costs:

- The deregulation and liberalization of electronic communication markets
- The privatization and "merchandising" of the public domain
- Awareness of the value of the spectrum
- Worldwide competition between multinational operators.

Spectrum management has thus to respond proactively to these trends, in three broad areas:

- Planning current and future use of the spectrum
- Management, which includes issuing authorizations and licences (as well as ensuring compatibility of uses and equipment)
- Monitoring and controlling spectrum use.

These areas call for the implementation of regulatory processes, which are defined in the ITU Radio Regulations (RR):

- Allocation (of a frequency band): *Entry in the national table of frequency allocations of a given frequency band for the purpose of its use by one or more specific services. Spectrum can be allocated on an exclusive basis (allocated to a single service) or a shared basis (shared by more than one service), and on a primary or secondary basis* (see definition in RR, p.8).
- Allotment (of a radio frequency or radio-frequency channel): *Entry of a designated frequency or channel in a plan for use by a specific service under specified conditions. The allocation is made by a competent conference, such as the World Radiocommunication Conference convened by the International Telecommunication Union*[7].
- Assignment (of a frequency or a radio-frequency channel): *Authorization given by a national regulatory authority for a given entity (e.g. a mobile telecommunication service operator or provider) to use a designated frequency or channel under specified conditions.*

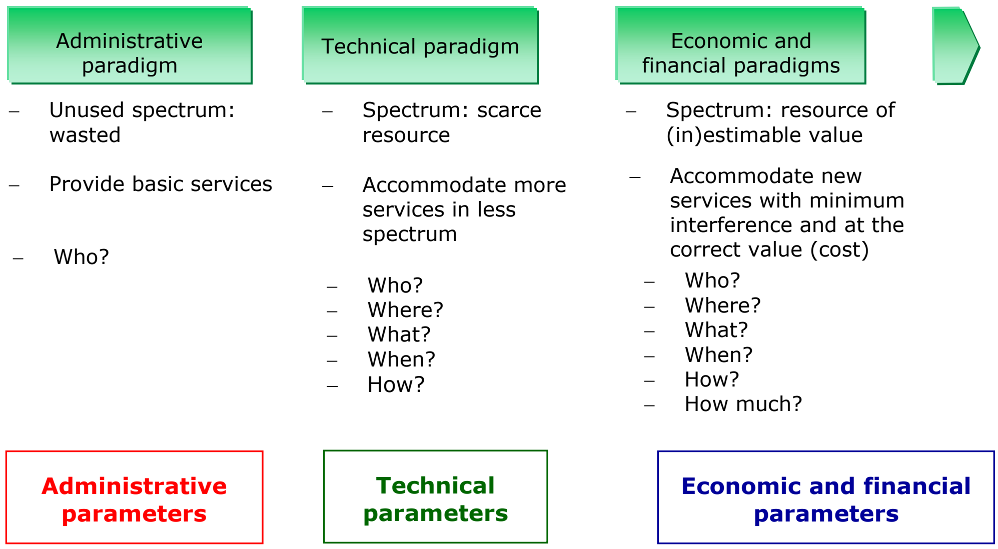
These processes and areas have to respond to today's paradigms from the administrative, technical and economic/financial perspectives, by addressing underlying questions and tasks, as illustrated in Figure 3.[8]

[6] ITU-D Study Group 2 report, fifth study period (2010-2014), *Resolution 9: Participation of countries, particularly developing countries, in spectrum management (*www.itu.int/pub/D-STG-SG02.RES09.1-2014)

[7] www.itu.int/en/ITU-r/conferences/wrc/Pages/default.aspx

[8] ITU-D Study Group 2 report, fifth study period (2010-2014), *Resolution 9: Participation of countries, particularly developing countries, in spectrum management (*www.itu.int/pub/D-STG-SG02.RES09.1-2014)

Figure 3: Spectrum allocation paradigms



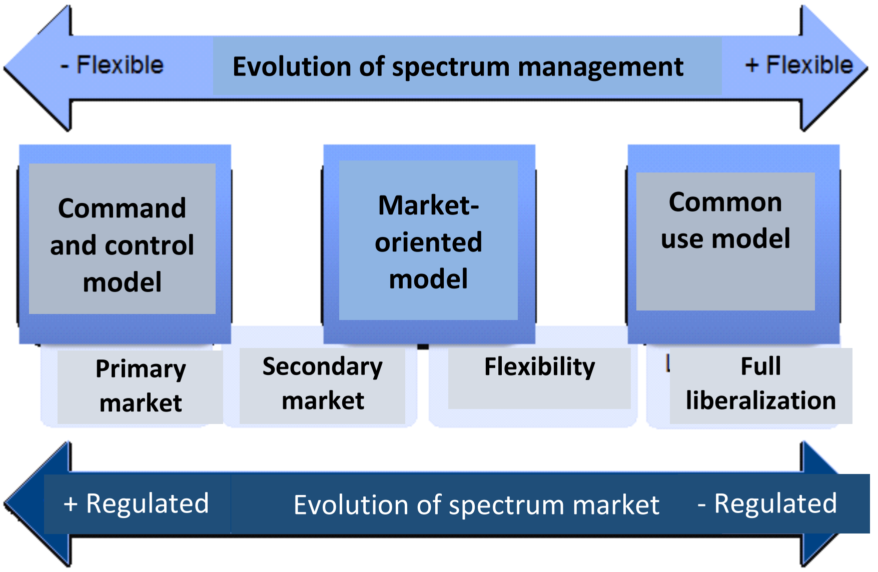
There are a number of administrative methods for assigning spectrum, also known as: command and control model (e.g. assignment of bands for public service use); market-oriented model (i.e. through licence auctions); or generic licensing (i.e. any user can access the band provided that and for as long as the user complies with the technical specifications set out in the generic licence[9]) (see Figure 4).

The primary market for access to spectrum use is founded mainly on the model of government-run auctions, while the secondary market allows an operator access to spectrum by means of a private commercial transaction. Such private contracts may require prior authorization from the regulatory authority, and may be structured on the basis of a short-term (one year) or long-term (> one year) lease.

As can be seen from Figure 2, the degree of flexibility in assignment depends on the model employed. In practice, spectrum assignment has tended in recent decades to move away from a command and control model towards a combination of the market-oriented and common-use open-access models. This evolution is guided by the principle that the latter two assignment models may better serve the goals of technical and economic efficiency. They will be looked at in more detail in the following sections.

[9] It is important to mention here that, strictly speaking, pursuant to Article 18 of the Radio Regulations, there is no such thing as unlicensed spectrum use. No. 18.1, §1.1 of the Radio Regulations states that: "*No transmitting station may be established or operated by a private person or by an enterprise without a licence issued in an appropriate form and in conformity with the provisions of these Regulations by or on behalf of the government of the country to which the station in question is subject (however, see Nos. 18.2, 18.8 and 18.11)*". Accordingly, some bands may be allocated for free use by systems such as Wi-Fi under generic licences (see section 3.4 below).

Figure 4: Spectrum allocation models



Source: Author

1.3 General principles of radio-frequency spectrum management

According to ITU-D[10], traditionally public authorities have often allocated frequencies for specific applications, and then assigned parts of the spectrum to entities responsible for using them for specific purposes based on the "first come, first served" principle. This approach is fast, practical and less costly, but has its limits in today's environment.

For this reason, modern spectrum management is geared towards optimizing the value of the radio-frequency spectrum. Such optimization is now becoming both necessary and sought after by public authorities for several reasons:

- to encourage an effective use of this resource which is not produced, is limited, and is in some cases scarce;
- the frequency spectrum has become an important means to develop countries' telecommunications;
- the budgetary income generated by the spectrum can contribute to countries' economic development;
- income from frequencies must contribute to improving the means used for spectrum management (monitoring, spectrum management information system, ...) and make it possible to fund refarming operations.

This optimization involves maximizing the attainment of three objectives: economic efficiency, technical efficiency and social benefit. This is no easy task, since these three objectives often conflict, obliging the regulator to decide on trade-offs.

From the perspective of **economic efficiency**, spectrum management seeks to maximize the added value of use of the services produced by the available spectrum. All frequencies, on account of their technical characteristics, can be used for more than one service. This is reflected in national tables of frequency allocations and databases of spectrum users, where a frequency band may be segmented

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[10] ITU-D Study Group 2 report, fifth study period (2010-2014), *Resolution 9: Participation of countries, particularly developing countries, in spectrum management* (www.itu.int/pub/D-STG-SG02.RES09.1-2014)

by sub-band, area and time. For example, the 700 MHz band in Latin America can be used equally by broadcasting services and by mobile services (pursuant to the ITU Radio Regulations and the provisions of other regional bodies such as the Regional Telecommunication Technical Committee for Central America – COMTELCA). Accordingly, the principle of economic efficiency holds that a frequency band must be allocated to the communication service that generates greatest economic value. We shall return to this point in the discussion of digital dividend.

From the perspective of **technical efficiency,** given that the spectrum is a scarce resource, the objective to be pursued through frequency management is maximum utilization. At the same time, one of the reasons why the spectrum has to be managed is interference.[11] Interference occurs when residual transmissions on neighbouring frequencies cause degradation in the quality of a communication. By setting conditions of use and specified technologies, the principle of technical efficiency serves to keep interference down to acceptable levels.

The third objective to be pursued is maximizing **social benefit**. Recognizing that telecommunications are a service for the public good, effective spectrum management enables service providers to access the spectrum in an environment of healthy competition. This idea can be illustrated by means of an example from the mobile telecommunication industry. Radio-frequency spectrum management allows multiple mobile operators to gain sufficient access to the resource to offer services on a competitive basis, as a result of which the end-user will benefit with wider coverage, lower prices and innovative products. Another aspect of the social objectives to be maximized is better access to telecommunication services that have a high socio-economic impact, such as mobile broadband.

In many instances, these three spectrum management objectives (economic efficiency, technical efficiency and social benefit) may conflict. For example, a spectrum assignment scheme may achieve optimum technical efficiency but not necessarily represent the best economic value. This is the case of assigning spectrum under a generic licence or through free access as against competitive licensing (auctions, "beauty contests", bidding, etc.). Economic research has shown that, while assigning frequencies by auction can maximize economic efficiency of the spectrum (in the short term), setting aside some frequencies for open access generates a greater economic surplus. This point will be expanded upon below in the analysis of generic spectrum allocation.

2 Radio-frequency spectrum assignment models

As mentioned above, radio-frequency spectrum management is guided by three alternative assignment models:

- **Command and control model:** This involves granting usage licences within a primary market, organized on the basis of administrative assignments.
- **Market-oriented model:** This includes holding auctions, secondary markets and sharing models.
- **Common-use model:** This assumes full liberalization (subject to the principles of no interference) in the use of spectrum.

[11] The Radio Regulations define "interference" as (No. 1.166): "*The effect of unwanted energy due to one or a combination of emissions, radiations, or inductions upon reception in a radiocommunication system, manifested by any performance degradation, misinterpretation, or loss of information which could be extracted in the absence of such unwanted energy*". They also define various types of interference, in particular, "harmful interference" (No. 1.169), which is: "*Interference which endangers the functioning of a radionavigation service or other safety services or seriously degrades, obstructs, or repeatedly interrupts a radiocommunication service operating in accordance with the Radio Regulations*". In this study, "interference" is assumed by default to mean "harmful interference".

Generally speaking, many countries' regulatory frameworks and spectrum management models employ a mix of these models, seeking the most effective combination of approaches to suit specific bands and each country's particular situation.

2.1 Auctions

In the early days of wireless communications (primarily maritime), as there were so few spectrum users, the risk of interference was minimal, with the result that use of the spectrum was completely free and unlicensed. The proliferation of radio stations in the 1920s prompted the US Congress to set up a telecommunication regulator empowered to grant licences for the exclusive use of bands of spectrum. Under this model, called command and control, the US telecommunication regulator assigned frequency bands through hearings coordinated by an administrative judge in which possible alternative assignments were put forward.

This model was criticized by Ronald Coase in his article published in 1959,[12] in which he asserted that the frequency assignment model "*should be determined by the forces of the market*" as an alternative to the command and control model. Coase, who was awarded the Nobel Prize for economics in 1991, suggested that the command and control model was not the economically most efficient way of assigning a scarce resource. He argued that, when a resource is scarce, the best way of distributing it is through a price-setting mechanism in order to ensure that the recipient of the frequency band will generate the greatest economic value. Consequently, Coase established that, in the same way as land is protected by clear property rights, the spectrum should be, too. The protection of spectrum property rights is irrevocable, guaranteeing the right to utilize the spectrum for a specified period and under specified conditions, so that it can be assigned as efficiently as possible. Thus, setting the price of spectrum by means of an auction will guarantee more effective assignment of its use than the command and control model. In a frequency band auction, the highest bidder is granted a licence to transmit and receive signals in the band acquired. This licence is protected by operating rights. On the basis of Coase's recommendation, in 1993 the US Congress empowered the telecommunication regulator to organize licence auctions. This method has since spread to most countries of the world, partly because it gives governments the possibility to generate significant revenues.[13]

Before the 1990s, the majority of countries assigned spectrum bands for the mobile telecommunication service according to the command and control principle, based on so-called "beauty contests". In this method, entities interested in obtaining a licence are assessed in terms of their coverage plans and technology. Thus, the regulator assigns the frequency band to the candidate that puts forward the most attractive cellular network deployment plan from the point of view of technological progress and territorial coverage.[14] During the 1990s, the auction model took hold in most countries of the world, partly because it gave governments the opportunity to generate significant revenues.

Auctions provide an effective reply to two questions: *Who to assign to*? and *How much to charge*? Auctions are an assignment mechanism that leads to transactions (assignment of resources and setting of prices) based on comparison of offers from those participating in the process. Generally, the auction process rules are announced in advance, and the prices paid are set by the participants according to their commercial strategy and capabilities.

The advantage of auctions resides in the fact that market prices for spectrum rationalize the availability of supply. Moreover, the winner is the bidder with the best business plan, rather than the company which gets lucky or whose presentation makes the best impression on the adjudicator. Last but not

[12] Coase, R.H. (1959). The Federal Communication Commission, Journal of Law and Economics, Vol, 2 (Oct.), 1-40.

[13] Extreme caution must be exercised when conducting spectrum auctions with the sole aim of maximizing such immediate revenues, there being a great risk of running counter to the technical and social objectives, and even the economic objectives in the medium and long term (the "winner's curse" penalizes not only the operator who over-values the spectrum, but also the regulator who witnesses a detrimental impact on the development of ICT networks and services).

[14] See Report ITU-R SM.2012-4, *Economic aspects of spectrum management*, p. 19.

least, the government, as the seller, collects maximum income. It is important to point out, however, that auctions may not always be the most suitable assignment mechanism for the following reasons:[15]

- Not all bands can be auctioned: e.g. frequencies allocated to aeronautical, maritime, etc. services do not fit into this "market forces" model[16]
- Limited technical requirements
- Auction does not necessarily achieve the highest social value from the spectrum on offer
- A poorly qualified candidate may win the licence
- A successful candidate may overbid in relation to the intrinsic value of the auctioned spectrum, even to the point of invalidating its business plan (the so-called "winner's curse")
- Uncertainty regarding demand, tariffs, etc.
- Possibility of collusion between bidders, resulting in a price which is lower than the intrinsic value.

Table 5[17] summarizes the advantages and disadvantages of the auction model, which may serve as a guide to determining in which cases to use auctions and how to conduct them.

According to ITU-D,[18] ten types of auction may be identified, namely: (1) open auction (public bids)/closed auction (sealed bids); (2) single-round/multiple-round auction; (3) single-object/multi-object auction; (4) sequential/simultaneous open auction; (5) English (ascending) auction; (6) Dutch (descending) auction; (7) single-round/sealed-bid/first-price auction; (8) single-round/sealed-bid/second-price auction; (9) simultaneous/multiple-round/ascending auction; and, finally, (10) clock auction.

Table 5. Advantages and disadvantages of auction models

Advantages	Disadvantages
• Relative maximization of revenue for the government • Optimization of spectrum (economic efficiency) • Opening up to competition • Relative speed of process • Transparency	• Limited technical requirements • Does not necessarily achieve the highest social value • A poorly qualified candidate may win the licence • Successful candidate may overbid (the so called "Winner's curse"): uncertainty regarding demand, tariffs, etc. • Possibility of collusion during the bidding

For the purposes of this study, the ten categories will be grouped into six types of spectrum auction, as follows: (1) first-price sealed-bid; (2) second-price sealed-bid; (3) ascending (English); (4) descending (Dutch); (5) multiple-round; and (6) simultaneous ascending multiple-round.

Here, the multi-object model refers to auctioning various bands together; in turn, it will be subdivided into simultaneous or sequential (in the latter case, the outcome of one auction sequence may be considered for conditions in respect of the following sequence (e.g. spectrum caps)).

In the **sealed-bid first-price** model, bidders tender simultaneous sealed bids in a single round, and the winner pays the price corresponding to the highest offer. The process begins with a presentation

[15] Source: ITU-D. *Resolution 9: Participation of countries, particularly developing countries, in spectrum management* (2010-2014), Geneva, p. 13.

[16] ITU-D Study Group 2 report, fifth study period (2010-2014), *Resolution 9: Participation of countries, particularly developing countries, in spectrum management (*www.itu.int/pub/D-STG-SG02.RES09.1-2014)

[17] ITU-D Study Group 2 report, fifth study period (2010-2014), *Resolution 9: Participation of countries, particularly developing countries, in spectrum management* (www.itu.int/pub/D-STG-SG02.RES09.1-2014)

[18] ITU-D Study Group 2 report, fifth study period (2010-2014), *Resolution 9: Participation of countries, particularly developing countries, in spectrum management (*www.itu.int/pub/D-STG-SG02.RES09.1-2014)

of interested parties and their prequalification, followed by the submission of bids. In some cases, the prequalification and tendering phases are combined in order to avoid candidates having prior knowledge of the identity of the bidders, which could introduce negative effects in the auction. Awarding the winner and setting the price are relatively simple, although in some cases this may require the use of algorithms to determine who has indeed won (in the event that bidding options are not clearly predefined).

In a **sealed-bid second-price** auction (also called the Vickery model, from the name of the academic who originally developed it), sealed bids are also tendered simultaneously, but the licence is awarded at the value of the second-highest bid. In a second-price auction, the winner only pays the price offered by the second highest bidder. In economic terms, this is equivalent to the opportunity cost resulting from the possibility of excluding the other bidders.

Sealed-bid models are attractive in that the limited information on participants and incumbent operators' strategy may open up an opportunity for the entry of new operators. Also, this model allows price to be combined with other features like coverage or type of technology to form a composite scorecard for determining the winner (which *de facto* reintroduces aspects of the "beauty contest"). Lastly, from the standpoint of the regulatory authority, sealed-bid models cost less to implement than multiple-round models.

Recently, auction models have moved away from sealed-bid arrangements towards multiple rounds.[19] In the **multiple-round model**, bids are progressively raised in each round. At the end of each round, participants obtain feedback on their position in the state of play. The winner pays the highest price bid. In the **ascending model** (also called English auction), progressively higher public bids are made, determined by the seller or the participants. In this case, the winner pays an amount marginally higher than the bid of the second highest bidder. In the **descending model** (also called Dutch auction), the seller publicly announces progressively lower prices. The winner pays the price bid. Lastly, the **simultaneous multiple-round model** is an extension of the previous model for the sale or assignment of more than one band at the same time.

The **multiple-round model** is advantageous in that it is easy to understand for bidders. Generally speaking, when an asset has a strong common value component, an open auction is more attractive for the government: skeptical participants have more confidence in the value of the asset when more aggressive bidders are making bids ("he knows something I don't"). It is for this reason that sealed-bid auctions attract expert participants (incumbents) and deter the less initiated (new entrants). The risk of the multiple-round auction is that it is more vulnerable to distorting mechanisms such as participants' revealing each other's strategy.

Auction efficiency hinges on the notion that the lot is assigned to the person who values it most and is willing to pay the highest price. Having regard to this definition, not all auctions are equally efficient. For example, the level of risk aversion may introduce distortions; or collusion and cooperation between participants may also undermine efficiency. Collusion is an arrangement by which various buyers share information or agree to act in a certain manner (cooperative strategy) to win the auctioned lot.

In the final analysis, from the regulator's perspective, various factors have to be taken into account in designing an auction and selecting the most suitable model, namely:

- Type of band(s) to be auctioned
- Current and future status of those bands
- Type of valuation of the band (private or common value)
- Participants' behaviour (neutrality or risk aversion)

[19] Some regulatory authorities are of the view that sealed-bid auctions are not conducive to maximizing bids (Santos, 2015).

- Desired characteristics for the new market
- Type and amount of information to be disclosed on the conduct of the auction
- Spectrum caps (multi-band, multi-auction)
- Medium- and long-term auction plans
- Coverage obligations
- Inherent tax liabilities
- Infrastructure sharing/secondary markets.

In designing an auction, the regulator has to consider a series of objectives to be achieved to the maximum extent possible. These include (not necessarily an exclusive list): promoting efficient assignment of spectrum, stimulating competition in the industry, encouraging participation in the auction, generating revenues for the government and increasing geographic coverage of networks.[20] The point to emphasize is that there is no single or "best" model. This means that there is no clear correlation between the auction model and the outcomes. Each model has specific features, each having a different appeal for governments and bidders. Ultimately, the auction model depends on the market structure (and the government's objectives in terms of developing an appropriate competition model).

A common phenomenon encountered in auctions characterized by incomplete information is the so-called "winner's curse". This is the situation that occurs when the winner of the spectrum auction has paid an amount for the licence that exceeds the amount of its economic value.[21] Thus, although the winner has obtained the licence, since it has paid in excess of the intrinsic value it is in a worse position than if it had lost the auction. This phenomenon becomes more serious as the number of participants in the auction increases. The risk for the NRA is that if the "winner's curse" is extremely severe, it may give rise to friction costs which are liable to affect investment in the future deployment of networks: overestimation of the economic value reduces the amount of investment allocated for construction of the new network and, consequently, may hamper its future deployment.

Generally speaking, the "winner's curse" could be mitigated by the auction's design. For example, in a multiple-round auction, bidders can have access to information on how much each of their opponents estimates the spectrum to be worth, thereby reducing uncertainty. Therefore, in the case of a multiple-round auction, one strategy to reduce the "winner's curse" is to give bidders time to evaluate information from their opponents and decide on their strategy and valuation. To this end, it is wise to announce the results of each round before launching the next one[22].

Finally, auctions are a market-based mechanism, and the fundamental requirement for the proper functioning of any market is a solid legal underpinning. This means that, for an auction to perform optimally, the nature of the right being auctioned (geographic coverage, available bandwidth, tenure of licence, etc.) as well as the accompanying responsibilities (licence conditions, service restrictions, equipment standards, etc.) should be specified as precisely as possible. Any uncertainty surrounding such factors as the length of tenure of the licence being auctioned will create confusion and may result in lower bids.[23]

When looking at these auction models, one must not lose sight of the fact that what is being auctioned is the right to operate a public asset, which makes it a significantly different situation from traditional auctions. Table 6 contains a brief comparative analysis.

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20 For example, in the frequency auction for 4G networks in Argentina, the regulatory authority imposed geographic coverage obligations along with deadlines by which they were to be met.

21 Thaler, Richard H. (1988). "Anomalies: The Winner's Curse". *Journal of Economic Perspectives* ***2*** (1): 191-202.

22 Industry Canada. *Consultation on Issues related to Spectrum Auctioning,* www.ic.gc.ca/eic/site/smt-gst.nsf/eng/sf09441.html

23 See Report ITU-R SM.2012-4. *Economic aspects of spectrum management,* p.27.

Table 6. Comparative analysis of traditional and spectrum auctions

	Traditional auction	Spectrum auction
Seller	Specialized agent	ICT regulator
Mission	Auction goods	Regulate the ICT market to protect the user and guarantee competition
Asset	Valuable material good	Scarce natural resource (property of the State, non-transferrable)
Deliverable	Ownership of the good	Operating rights for a limited tenure under specified conditions Indispensable (and irreplaceable) for broadband universal service
Auction objective	Collect maximum revenue – Auction is end in itself	Guarantee provision of the service in a competitive environment – Auction is a means to an end
Participants	Customers interested in the good	Mobile operators
Winner's curse	Irrelevant	Highly sensitive, compromises the mission
Indicators of success	$, $$, and more $$$	Social and economic benefit: $$ in short, medium and long term Impact on tariffs and services Contributions to universal service Effect on competition (avoid dominant positions)
Indicator time-frame	Immediate	> 10 years
Preconditions	Performance bonds	Technical and financial indicators Spectrum caps Coverage obligations
External variables	Few or none	Short-, medium- and long-term band availability Regulatory conditions: • Secondary market for spectrum • Infrastructure sharing • National interconnection networks • Current and future competition status • Universal service objectives

Source: ITU/BDT Workshop on Guidelines on the policy and economic aspects of the assignment and use of the radio-frequency spectrum (Nicaragua, 4 September 2015) – ITU/BR presentation[24]

It is therefore important to exercise extreme caution with this mechanism, which cannot be applied across the board to all spectrum. Indeed, as stated in the ITU Handbook on National Spectrum Management:[25]

Auctions are not a universal panacea and are only suitable for specific licences and conditions. They are not suitable if the spectrum right cannot be defined properly. They are also not suitable for high-volume, low-value licences nor for application to socially desirable services nor when there is no or limited competition. In fact, the single most important factor for auctioning a licence is that the

[24] www.itu.int/en/ITU-D/Regional-Presence/Americas/Pages/EVENTS/2015/0831-NI-cosydirc.aspx
[25] ITU Handbook on National Spectrum Management, Edition 2005, pp. 195-6.

winning applicants' services should face competition and a prerequisite for auctions is therefore that effective competition legislation exists to ensure the bidders do not form price-fixing arrangements.

Auctions may be inefficient or impractical for certain services or situations. One case is where there is no competition for spectrum. This could occur, for example, with fixed microwave systems where there are many individual links with narrow beamwidths and very exact locations, or where potential operators see little prospect of achieving a realistic return on their investment within a reasonable timescale. A second case is where providers of socially desirable spectrum-using services such as national defence or scientific research may have difficulties in placing a financial value on spectrum, which could lead to those services being under-provided to society if all providers of spectrum-using services faced auctions.

Furthermore, it is essential for the NRA to know everything about the current and future use of the bands to be auctioned. Indeed, as clearly stated in the ITU-D Report:[26] "*Before participating in a frequency auction, bidders will want to know the degree of protection against harmful interference they may expect with the spectrum that is auctioned, as well as the measures they are expected to take to avoid causing harmful interference to other users or suffering such interference. They will also want assurance that the State will ensure that this regime for protection against interference is properly enforced".*

For this reason, the quality of the database of spectrum users (licences, licence-holders, georeferencing, technical, financial and legal conditions, time-frames, etc.) and systems for monitoring and controlling spectrum use play an essential role. Low reliability of spectrum management and monitoring systems creates great uncertainty among stakeholders as to how "clean" the band is and the underlying risks of interference, which has an adverse effect on the band's value.

In addition, how efficiently the regulator carries out its "corrective" role – revocations and appropriate sanctions in respect of anyone causing harmful interference – determines the administration's legal ability to protect the rights or privileges of spectrum users and, ultimately, organize successful auctions.

It has to demonstrate both its technical capability (with the above-mentioned systems) to identify and locate interference, and its legal capability to act promptly in eliminating such interference.

Spectrum regulators should therefore attach importance to modernizing and optimizing their respective management and monitoring systems, and their associated databases, as well as their legal capability to prevent and rectify unauthorized emissions, as essential prerequisites for holding auctions.

2.2 The concept of secondary market

In markets that have matured to a greater level of flexibility and the implementation of secondary markets, regulatory mechanisms have been introduced with the aim of cutting down on the administrative restrictions on licensing, allowing licences to be subdivided and recombined in new configurations. In 2010, according to ITU, 11 countries possessed a secondary frequency market, and 12 were planning to implement a secondary market in the future[27] Among the most well-known examples, we may mention the standard training units (STUs) in Australia,[28] management rights in New Zealand[29] and partial leasing and sub-leasing possibilities in the United States. At the European level, there are a number of directives: Directive 2009/140/EC of the European Parliament and the Council, of 25 November 2009, amending Directives 2002/21/EC on a common regulatory framework

[26] ITU-D Study Group 2 report, fifth study period (2010-2014), *Resolution 9: Participation of countries, particularly developing countries, in spectrum management (*www.itu.int/pub/D-STG-SG02.RES09.1-2014)

[27] See ITU. ITU-D Study Group 2 report, fourth study period (2006-2010), *Resolution 9 (Rev. Doha, 2064): Participation of countries, particularly developing countries, in spectrum management,* Geneva, p.8 (www.itu.int/pub/D-STG-SG02.RES09-2010)

[28] Australian Communications and Media Authority. *Spectrum Trading: Consultation on trading and third party authorisations of spectrum and apparatus licences.* August 19, 2015.

[29] Ministry of Economic Development. *Review of Radio Spectrum Policy in New Zealand*. Auckland, 2005.

for electronic communications networks and services, 2002/19/EC on access to, and interconnection of, electronic communications networks and associated facilities, and 2002/20/EC on the authorization of electronic communications networks and services. France and the United Kingdom are reference cases for the rapid incorporation of these directives in their national law.

The option of temporarily surrendering spectrum usage rights for a period of time could come to be more important than the option of selling spectrum, as a way of channeling into a secondary market the supply of spectrum which is being underused in the short term. Since we are typically dealing with long-term licences that have been granted through competitive mechanisms, the licence-holder is unlikely to want to relinquish the licence, or even part of it, but with the incentive of a rent may be willing to surrender temporary or shared use.

With respect to secondary markets, in some countries licences can be transferred without any significant restrictions, subject to some degree of power of veto on the part of the regulator for technical or exceptional reasons. In such cases, the national competition authority often intervenes to eliminate restrictions on licence-holding by foreigners. This avoids problems of excessive concentration of frequencies, which leads to a deterioration in services or a less healthy business climate.

Flexibility of use, together with the possibility of reconfiguring licences, are strong factors in fostering supply and demand for underused spectrum in secondary markets. Experience appears to support the argument that the more flexible the service, technology and configuration (of bands, geographical areas, periods of use, etc.), the greater the opportunity for third parties to offer services and ultimately the more effective the development of a secondary spectrum market. Some countries allow trading and transfer of licences among operators against financial consideration, generally subject to the technical and economic endorsement of the respective regulator. On the basis of the information contained in the ITU ICT-Eye,[30] some countries in Latin America (Guatemala, El Salvador, Chile, Mexico and Uruguay) allow spectrum trading among operators, while the main benchmark countries in Europe (United Kingdom, Spain, Finland, Denmark) and North America (United States and Canada) possess a secondary spectrum market. By way of example, in this case the regulator's role consists in approving and verifying the transfer of rights in order to avoid the possibility of negotiations seeking to establish dominant positions in respect of the spectrum and to monitor and ensure efficient use of the spectrum.

The secondary market may also entail certain disadvantages, such as the fact that the resale of frequencies will require administrative provisions, which are not covered in the original regulatory framework. Besides this, there is room for distortion of competition insofar as the prices obtained on the public market through auctions are different from those arising from the secondary market. Lastly, the mechanism can also give rise to speculative manoeuvres linked to the accumulation of unused spectrum.

30 ITU's ICT-Eye database: www.itu.int/net4/itu-d/icteye/

Box 1 – Experience in Latin America

In Latin America, efficient use of the spectrum, as a guiding principle in the regulatory frameworks for the management and administration of this resource, has prompted several administrations of countries in the region (e.g. Mexico, Chile, Colombia) to analyse their regulatory regimes with a view to considering incorporating therein mechanisms for managing and assigning the spectrum based on criteria of technical, economic and social efficiency. This trend is emerging as a response to the increasing demand for radio-frequency spectrum and the identification of the spectrum as a scarce resource, the dizzying pace of technological development in the various sectors of the economy and the digitization of telecommunication networks and services. Nevertheless, this process of transition in the spectrum management scheme calls for the analysis and development of technical and regulatory tools and instruments to support the implementation of flexible spectrum management mechanisms, while ensuring the smooth operation of telecommunication services as well as economic and social efficiency in the spectrum assignment processes.

At present, although several countries of the region have included sale or rental of licences for use of the spectrum as a feature of the secondary market, we have not witnessed any major transactions.[1] There are a number of plans to move forward with such transactions, although none of the regulatory authorities wants to be the first to authorize them, since the concept is still extremely new in the region. For example, Claro wishes to acquire 10 MHz in the AWS band in Peru from Telefonica, but the regulator has not yet approved the transaction. In Chile, as a consequence of the fact that spectrum held by VTR and Nextel in the AWS band is unused and VTR is becoming an MVNO, moves are afoot to bring in a law allowing sale of the licences on the secondary market. This proposal is currently under consideration in the congress. In Colombia, following its merger with UNE, the mobile operator Tigo has been given a period of two years within which to sell or lease to another operator the spectrum in the bands where its assignment limit is exceeded. However, this has not yet been implemented.[2]

1 The sole exception is the case of Puerto Rico, where AT&T has completed the purchase of spectrum in the 700 MHz band from another operator.

2 In Paraguay, the spectrum in the AWS band currently in the hands of COPACO could be reassigned for inclusion in this year's auction; however, this operation would not be carried out in the secondary market but would be undertaken through reassignment/reorganization.

2.3 Spectrum sharing

Spectrum sharing is a possible means of improving spectrum use that depends on regulatory actions. It consists in granting more than one user the possibility to use a given frequency band. Various spectrum-sharing models may be identified. Five of these are presented in this section, namely:

- Unlicensed spectrum (common-use bands)
- Combination of spectrum from various licensed operators
- Use of software defined radio (SDR) and cognitive radio system (CRS)
- Sharing of spectrum using small cells
- Combinations of wireless networks (e.g. routing cellular traffic through Wi-Fi sites, offload).

2.3.1 Unlicensed spectrum (common-use bands)

The most frequent spectrum-sharing model is the establishment of bands for common use. Not all spectrum bands are assigned on the basis of frequency auctions for exclusive use. In this case, the use of the bands in question is free and is regulated solely on the basis of technical restrictions and type-approval of equipment in order to limit interference to other services. As an example, Table 7 shows the frequency bands in the United States that have been assigned on a common basis without the need to acquire a specific licence.

Table 7. United States – Standards and technologies operating in bands for common use

Technical standards	Bands	Geographic coverage	Bandwidth	Applications
Wi-Fi (802.11b, 802.11g)	2.4 GHz 3.6 GHz 5 GHz	Inside : 38 m Outside: 125 m	Up to 54 Mbps	Computers Printers Mobile Phones Tablets
Bluetooth (802.15.1)	2.4 GHz	Inside- Short distance	1-3 Mbps	Audiophones PC Networks Scanners Credit-Card Terminals
ZigBee (802.15.4)	915 GHz	75 m	250 kbps	Light switches Electricity meters Traffic management systems
WirelessHART (802.15.4)	2.4 GHz	Inside: 60-100 m Outside: 250 m	250 kbps	Monitoring industrial processes Monitoring electricity consumption Remote equipment maintenance
WirelessHD	60 GHz	30 feet	28 Gbps	HD televisions
WiGig (802-11ad)	60 GHz	5-10 m	6 Gbps	Intelligent telephones Tablets PCs and peripherals TV and peripherals Digital cameras Video cameras
RFID	50-500 kHz 13.56 MHz 0.9 to 2.5 GHz	Up to 29 inches	Read-Only: 8.75 kbps active read-write: 3 kbps	Monitoring physical assets (e.g. Containers) Livestock monitoring Credit-card payments Toll systems Supply-chain management

Source: Compiled by the author

In this case, any operator or equipment manufacturer may introduce a product as long as the product meets certain technical requirements. Currently, the application of common bands is becoming more widespread in many industrialized countries (United States, United Kingdom, Canada).

It should be noted that although these bands/equipment are commonly referred to as "unlicensed", in reality a licence is in fact required, because from a regulatory standpoint they are extensions of a specific licence under which their operation has already been authorized for the general public by means of a generic authorization (licence) that includes technical and operating conditions which have to be strictly obeyed in operating the equipment, so as to guarantee that their use does not cause interference to other similar equipment or other services. The expression "unlicensed" should therefore not be misinterpreted as leave to operate such equipment freely, since any modification of the preset parameters authorized constitutes a breach of the generic licence.

2.3.2 Combination of spectrum from various licensed operators

This sharing model assigns given frequency bands for cooperative use in restricted geographic areas. The concept has been developed by New Zealand in what it calls "licensed spectrum parks" (see Katz and Beltrán, 2015). The New Zealand Ministry of Business, Innovation and Employment (MBIE), which manages the spectrum, has set aside the band from 2 575 to 2 620 MHz (with a 5 MHz guardband requirement) to be assigned in spectrum parks. By September 2009, no fewer than 80 licences had already been granted.[31]

The concept of spectrum park "*seeks to encourage a flexible, cooperative, low-cost and self-managed approach to allocation and use*" in the band concerned (MBIE, 2010). In this way, the park allows shared use of a band of spectrum, with the aim of promoting efficient assignment and innovation in the use of the spectrum.

Spectrum parks are an alternative to national licences that allow small operators wishing to specialize in a specific geographic area to do so without having to pay the large sums of money typical of spectrum auctions. By agreement with the Ministry responsible for assigning frequencies, spectrum parks are intended for "regional and local services" where licence-holders require "a degree of coordination or sharing" (MBIE, 2010).

In this model, licences are assigned on a first-come, first-served basis. Licence-holders must pay a fee for annual administrative costs, which include charges for the administration and leasing of resources. This does not exceed NZD 300 (approximately USD 195) per licence per year. Where more than one enterprise is interested in obtaining a licence for a specific area, the Ministry has a mediation process in place to decide which will be successful. The first round of negotiation is based on private talks between the candidates for the licence. If this fails, the next stage is a lottery. The regulator has thereby transferred responsibility for deciding who receives the licence to the candidates: they are the ones who must make reasonable efforts to reach an agreement, which may even include sharing the licence. Sharing conditions include terms of use to avoid interference.

Where two candidates come to a sharing agreement, the licence is awarded to both. Sharing may occur between two or three operators operating in the same frequency, or the allocated area may be divided among them. If possible, it is agreed that the "park" will be administered in a coordinated manner. Any disputes concerning interference must be resolved on the basis of mediation, following a set procedure.

In Latin America, there are some countries where spectrum bands are allocated for research and development purposes in the field of new wireless technology.

2.3.3 Use of software-defined radio and cognitive radio systems

Spectrum can also be shared using technologies that bring a certain degree of flexibility to spectrum use. Software-defined radio systems allow the operational parameters of radio frequencies, including band selection, type of modulation and output power, to be set or changed by means of software. On the other hand, cognitive radio systems allow transmitters and receivers to adapt dynamically and independently to operational parameters and protocols based on information taken from the operating and geographic environment[32].

The economic value of these systems remains difficult to assess because the technology is still in its infancy. However, researchers have started to estimate their potential economic impact by looking at cases where sharing occurs. For example, cognitive radios allow spectrum to be shared between

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31 See Ministry of Business, Innovation and Employment (2010). *Managed Spectrum Parks Allocation Rules.* New Zealand Government. www.rsm.govt.nz, and Ministry of Business, Innovation and Employment (2009). *Managed Spectrum Parks: Park Rules*. New Zealand Government, www.rsm.govt.nz .

32 International Telecommunication Union. *Definitions of Software Defined Radio (SDR) and Cognitive Radio System (CRS).* Report ITU-R SM.2152 (09/2009)

primary and secondary licensees by enabling the efficient control of spectrum usage through rules established in a negotiation channel. Alternatively, the primary licensee can lease its resources flexibly using cognitive technology. This enables higher levels of efficiency than those traditionally achieved on the basis of exclusive property rights[33].

These new technologies provide instant intelligent management for spectrum resources, opening the door to new applications such as TV White Space. However, as happens with all developments in the field of telecommunications, once the new technologies reach the market, laboratories are confronted with the real world and must respond to challenges such as:

- Quality of service: the concept of shared use under a general licence inherently entails a no protection/no interference operating regime, so, as with Wi-Fi, all terminals must share the available spectrum at a given moment in a particular area. This being the case, how can each terminal guarantee a minimum level of quality of service despite not having a guaranteed minimum bandwidth?
- Last-mile and/or transport network solutions: how can the problem of interference with primary/secondary stations be managed in either case?
- The first approach also involves the use of embedded chips: how can critical mass be achieved to create a mass market so that the price of terminals will be sufficiently low?
- How should we manage the risk of a future licence being issued to a primary service station to operate a channel that unlicensed devices in the area use?

Taking these issues into account is the best way of ensuring the long-term stability (business model) of a project of this kind.

2.3.4 Spectrum-sharing using small cells

When the primary licensee uses spectrum in remote areas, this spectrum can be reused by small cells in high-demand urban areas that are far away from the remote location. For example, the United States telecommunications regulator allows shared-spectrum use and the deployment of small cells in the 3.5 GHz band, where maritime radar is the primary user (short-range devices (SRD)).

The use of small cells is subject to various factors. First, the level of protection against interference caused to primary and secondary services must be considered, which has an impact on small-cell coverage. Second, geographic spectrum use by the primary or secondary user must be assessed, which affects where small cells can be deployed. Third, consideration must be given to whether the spectrum frequency band and its propagation characteristics match those needed by these cells. Lastly, it is important to establish international harmonization of the shared spectrum band for use by mobile broadband, which may result in greater economies of scale.

2.3.5 Combining networks

Combining Wi-Fi and cellular technologies that operate in different spectrum bands means that a large amount of the increase in wireless traffic can be accommodated. Wi-Fi technology is already used for routing a high proportion of wireless traffic. Analysts estimate that 40 per cent of wireless traffic (mainly Internet access) is routed via public and private Wi-Fi locations[34]. Cisco estimates that the average global wireless data consumption is four times higher in Wi-Fi locations than on cellular networks, at 55 MB and 13 MB respectively[35]. As is to be expected, some industrialized countries like the United States have reached a more advanced level of Wi-Fi routing than the rest of the world,

[33] Uusitalo, M., Wijting, C., Rantalainem, T., Berg, K., Klemettila, A. and Niva, I. *Different approaches to estimate the value of cognitive radio*. Aalto: Nokia Research Center.

[34] Sources: Cisco (38.5%); Juniper Research (40%).

[35] Cisco (2013).

although to some extent they show a possible way forward for other countries. For example, based on a sample of 200 000 users in the United States, Mobidia estimates that, in January 2012, 88 per cent of smartphone users used Wi-Fi locations, with a traffic routing factor of 63.4 per cent.[36]

The economic value of combining cellular networks and Wi-Fi can be calculated on the basis of the benefit derived from the reduced congestion for cellular operators (Bazelon, 2008). Furthermore, wireless service users obtain value as a result of being able to access the Internet without, in many cases, having to pay transport costs, or else they benefit from lower power consumption (and therefore longer battery life)[37] and higher access speeds (Cui et al, 2013).

In summary, as a complement to cellular networks, Wi-Fi locations mean reduced mobile Internet access costs, lower capital investment in mobile networks and higher Internet access speeds.

2.4 Conclusion

Building on spectrum engineering practices, and with the underpinning of international trends and recommendations as well as ITU-R Recommendations, various mechanisms have been identified based on, among other things, frequency-band sharing; infrastructure-sharing; geographic spectrum use and geolocation databases to make use of white space; and cognitive and software radio techniques. All of the foregoing, accompanied by flexible arrangements for accessing spectrum, converge into innovative mechanisms based on licensed/authorized shared spectrum access, whether static or dynamic (dynamic spectrum access (DSA)), with regulatory structures that combine spectrum allocations through individual licences, light licensing and spectrum with general permits, or, by introducing secondary spectrum markets, with structures directly related to certificates of competence.

What are regulatory decisions based on when it comes to deciding about the possibility of sharing spectrum rather than allocating it to exclusive uses? The key decision is whether an established user should be removed and use of the band given to a new user or whether the band should be declared shared spectrum. Bazelon and McHenry (2013) give four scenarios for making such a decision:

- If the value of the spectrum to the new user is greater than the cost of removing the established user, reallocation increases the social benefit.
- If the costs of removing the established user exceed the value created by the new user, it is not worth reallocating the spectrum.
- If opening up the band to a group of new users creates more value than the established user loses, sharing the spectrum yields increased benefit.
- And if the established user's loss is greater than the value created by allowing a group of new users to share the band, the decision to share does not increase the benefit.

From a technical standpoint, one of the major concerns for spectrum-sharing arrangements is the potential for harmful interference that would end up affecting the operation of telecommunication services. This calls for a precise inventory of spectrum users (licensees, authorized users, identified free-use bands, etc.) and studies of the development of telecommunication systems using techniques based on obtaining information from the radio-frequency environment, such as sensors, cognitive pilot channels, dynamic frequency selection, software-defined radio and cognitive radio, among others. In other words, the inclusion of mechanisms that relate to models geared towards common spectrum use markets and models involves developing regulatory and technical rules, policies and tools for the entire spectrum management cycle: planning, allocation, allotment, assignment and monitoring.

[36] Informa (2012). *Understanding today's smartphone user: demystifying data usage trends on cellular & Wi-Fi networks*.
[37] Lee et al. (2010) estimate that WiFi routing saves 55% of battery charge.

3 Economic and market-related aspects to consider when assigning and using radio spectrum

3.1 Spectrum valuation methodologies

How is the price of spectrum determined? A study commissioned by the International Telecommunication Union[38] suggests three possible valuation scenarios. The first involves assignment of spectrum through an auction. In such cases, an indicative value of the spectrum is required, usually expressed as a reserve price. The second scenario involves resale of the licence by the original licence holder in the secondary market. This involves determination of prices in order to obtain an optimum price point in the transaction between seller and buyer. In the third scenario, spectrum use requires payment of recurring charges (taxes and duties). In these cases, payments are based on incentives for use.

In view of the considerable uncertainty in determining spectrum value, NRAs tend to use a range of different valuation methodologies in order to calibrate the different estimates obtained. The most common methodology involves the use of comparable results (*benchmarking*) based on the outcome of previous auctions or secondary transactions, although three other methodologies are also used: avoided costs models, business case analyses, and opportunity cost estimates. **Avoided costs models** calculate the investment that would be required from operators to respond to the increase in network traffic if they had no access to the spectrum in question. **Business case estimates** involve calculation of financial profit (in terms of discounted cash flows) derived from access to frequency bands. **Opportunity cost estimates** are based on calculation of the value generated by use of spectrum in various alternative mobile telecommunication applications. The following sections focus on details of each methodology and conclude with an account of the way in which they are used to determine the price of spectrum in a potential auction.

3.1.1 Use of comparable results (*benchmarking*)

Use of comparable results (commonly referred to as *benchmarking*) is the most commonly used spectrum valuation methodology. Comparable results can be analysed in two ways:

- By collating and normalizing auction prices obtained in cases similar to the country for which the results will be used (for example, neighbouring countries);
- Through econometric analysis, which allows different cases to be included taking account of socio-economic or topographic differences.

This methodology involves the collation of data on prices paid in other spectrum auctions or transactions, which is possible in the case of spectrum for cellular telecommunications but not in the case of spectrum available for satellite services or microwave links. The main advantages of this methodology lie in the simplicity of collation and communication and in the fact that prices can easily be verified. The drawback is that comparable data may not necessarily reflect the specific conditions of the country for which the results of the analysis are used. For example, the value generated by a spectrum auction varies according to the market in which the spectrum is used. In addition, the selection of data may have a significant impact on the results of the spectrum price to be estimated.

Conditions that affect the price include the national financial and fiscal framework, parafiscal obligations incumbent on the regulator (universal fund, and so on), coverage obligations, spectrum caps, short- and medium-term availability of bands, licence period, and renewal options.

To overcome these drawbacks, this methodology requires normalization of the data used (i.e. they must be considered together with the variables that allow comparability). The factors to be

[38] Alden. J. *Exploring the value and economic valuation of spectrum*. Geneva: International Telecommunication Union (ITU/BDT), April 2012 (www.itu.int/pub/D-PREF-BB.RPT3-2012).

considered in compiling comparable spectrum price data include the characteristics of the frequencies to be auctioned (bands and quantity of spectrum), conditions of sale of the licence (licence period, obligations regarding coverage, etc.), the timing of the auction in terms of market development, economic and structural factors (size of the economy, projected growth, income levels, population density and degree of urbanization), specific aspects relating to the auction participants (use of the spectrum that is to be acquired, strategic objectives of potential buyers), and specific features of the auctions (reserve price, pre-established limits as regards the quantity of spectrum that can be acquired by each operator).

Key variables that must be collected include the following:

- Characteristics of the frequencies to be auctioned: these include the frequency range, the technologies and services that might be used in the frequencies concerned, and the amount of spectrum available. The data used must correspond to similar frequencies; differences in frequency allocation plans must be considered, and the information compiled should preferably relate to countries with similar plans.
- Licence characteristics: these must include the terms of sale of the licence, including the period of validity and coverage obligations if any.
- Timing of the auction: data from auctions held a considerable time ago may not be suitable, given that commercial, industrial and technological conditions may have changed; updated information is therefore required.
- Specific valuation factors pertaining to the auction participants**:** these depend on the planned used of spectrum to boost company profitability (increased revenue or reduced costs) and market expectations. Variables include licences held by auction participants, deployment of their networks, their strategic objectives and market expectations.

Once cases have been selected with results that are valid in terms of comparability, the normalized values must be calculated (that is, where they are corrected for market differences). The three indicators that should be used are:

- Value per MHz per head of population in real terms
- Value per MHz by per capita GDP
- Value per MHz per head of population, adjusted by purchasing power parity
- All the above by year (taking account of differences in licence periods).

The first two are more widely used than the third, although the third has a major advantage in that it incorporates the level of economic development (and thus market potential) in the normalization by population. On the other hand the drawback of the first two lies in the fact that they tend not to be very effective in the context of countries with high rates of inflation. In general terms, use of the three indicators is recommended in order to identify discrepancies in their estimated values and ensure equivalence for similar time intervals.

In addition to normalization by MHz, population and per capita GDP, compilation of price data in each comparable auction must be calibrated in terms of total value collected (in which case annual payments for licence use must be included in addition to the price paid when the auction is concluded) and licence period. At the same time the prices must also be converted into a single currency, using types of exchange adjusted to purchasing power parity and inflation.

Once data on prices obtained by auctions in each country have been collected and normalized, it is important to consider prices in comparable frequency bands in order to calculate averages with a view to estimating the potential value of the spectrum to be auctioned. In the event that some of the cases to be considered in the average include countries with particular characteristics such as limits on the amount of spectrum that can be acquired by an operator, such cases must be excluded or assigned a normalizing weighting. If there are not sufficient examples in specific frequency bands, cases will need to be aggregated in groups of bands with similar signal propagation characteristics (for example, aggregating the 800 MHz band in Europe and the 700 MHz band in the Americas for 4G, or the AWS band in the Americas with the 2.1 GHz band in Europe and Asia).

Table 8 shows an example of comparable cases for the purpose of determining the price of spectrum in Latin America.

Table 8. Latin America: Spectrum auctions (2006-2015)

Country	Year	Frequency	Offer	Auction proceeds (USD million)	Price per MHz per head of population (USD)
Venezuela	2007	1 900 MHz	60 MHz	240	0.145
Peru	2007	850 MHz	25 MHz	22	0.031
Peru	2007	1 900 MHz	35 MHz	27	0.027
Panama	2007-8	1 900 MHz	80 MHz	229	0.832
Chile	2009	1 700 MHz /2 100 MHz	90 MHz	18	0.012
Mexico	2010	1 700 MHz /2 100 MHz	30 MHz	405	0.114
Mexico	2010	1 900 MHz	30 MHz	217	0.061
Mexico	2010	1 700 MHz /2 100 MHz	30 MHz	14	0.004
Brazil	2007	1 900 MHz/2 100 MHz	90 MHz	3 096	0.178
Brazil	2010	1 900 MHz/2 100 MHz	20 MHz	712	0.179
Colombia	2010	1 900 MHz	20 MHz	22	0.043
Colombia	2010	2 500 MHz	50 MHz	42	0.018
Costa Rica	2010	Various	110.4 MHz	170	0.286
Nicaragua	2010	1 900 MHz	50 MHz	12	0.042
Brazil	2012	2 600 MHz	120 MHz	1 396	0.057
Chile	2012	2 600 MHz	120 MHz	12	0.006
Colombia	2012	1 900 MHz	10 MHz	51	0.043
Venezuela	2012	1 800 MHz	30 MHz	85	0.095
Bolivia	2013	700 MHz	24 MHz	19	0.076
Colombia	2013	1 700 MHz	90 MHz	270	0.063
Colombia	2013	2 600 MHz	100 MHz	145	0.030
Honduras	2013	1 700 MHz	80 MHz	24	0.038
Peru	2013	1 700 MHz	80 MHz	257	0.105

Country	Year	Frequency	Offer	Auction proceeds (USD million)	Price per MHz per head of population (USD)
Uruguay	2013	1 700 MHz	60 MHz	68	0.333
Uruguay	2013	1 900 MHz	60 MHz	47	0.229
Argentina	2014	700 MHz	90 MHz	1 044	0.269
Argentina	2014	850 MHz	8 MHz	45	0.130
Argentina	2014	1 700 MHz	90 MHz	1 000	0.258
Argentina	2014	1 900 MHz	30 MHz	163	0.126
Bolivia	2014	1 700 MHz	30 MHz	23	0.073
Brazil	2014	700 MHz	60 MHz	2 410	0.195
Chile	2014	700 MHz	70 MHz	22	0.018
R. Dominicana	2014	900 MHz	20 MHz	28	0.134
R. Dominicana	2014	1 700 MHz	40 MHz	42	0.101
Venezuela	2014	2 600 MHz	80 MHz	240	0.098
Venezuela	2014	1 700 MHz	40 MHz	148	0.120
Ecuador	2015	1 700 MHz	40 MHz	120	0.185
Ecuador	2015	1 900 MHz	70 MHz	210	0.185

Note: For Auction 21 in Mexico the assignments to Nextel and those of other operators were separated.

Source: Regulatory authorities

As can be seen in Table 4, all other conditions in the bidding process being equal, the principal determining factor in spectrum price is a country's wealth (in terms of GDP) and population. For normalization purposes, the standard measure used is the price paid per MHz per head of population (USD/MHz/POP). The aim of this section is to establish a way of estimating the expected price on the basis of past data and macroeconomic indicators.

It is nevertheless important to emphasize that the type of auction and the licence conditions have a substantial effect on the price to be paid. Restricting the number of potential bidders reduces market depth, which in turn results in lower prices. There are a number of such cases in the region, including the assignment of the 1 700/2 100 MHz band in Chile (2009) and Mexico (2010), in which restrictions were applied on participation of existing companies (for example, spectrum caps) or where criteria other than economic return were considered;[39] the auction yielded only USD 0.012 and USD 0.004 per MHz per head of population, respectively, in each country. Similarly, where coverage or investment conditions are imposed, expected cash flows are reduced, which has an adverse effect on the price that can be obtained. Finally, recurring spectrum charges, which vary considerably from country to country, also have a major impact on cash flows and thus on the auction value obtained.

In 2006 in the United States, Auction 66 for 90 MHz in the 1 700/2 100 MHz band collected USD 13 700 million, equivalent to USD 0.508 per MHz per inhabitant. Auction 73 of 62 MHz in the 700 MHz band collected USD 18 959 million, equivalent to USD 1.006 per MHz per inhabitant. In Germany in 2010, 60 MHz were auctioned in the 800 MHz band and the auction collected €3 576 million, equivalent to

[39] The principal criterion applied by Chile was best coverage in the shortest time.

USD 1.034 per MHz per inhabitant. In other words the normalized amount paid was similar to that obtained in the United States.

In 2010 Mexico auctioned 30 MHz in the 1 700/2 100 MHz for USD 405 million, equivalent to USD 0.12 per MHz per inhabitant, which means that the discount in relation to the auction of the same band in the United States four years earlier is approximately 76.3 per cent. In Brazil in the same year, the auction of 20 MHz in the H-band (1 900/2 100 MHz) collected USD 712 million, equivalent to USD 0.187 per MHz per inhabitant, involving a discount compared to the United States of 73.7 per cent. In Peru in 2007, 25 MHz were auctioned in the B-band (850 MHz) and 35 MHz in the D- and E-bands for USD 22.2 million and USD 27 million respectively, yielding respectively USD 0.033 and USD 0.28 per MHz per inhabitant, with an implicit discount with regard to the United States of on average 93.5 per cent. In Colombia in 2010, 20 MHz were auctioned in the 1 900 MHz band for USD 220 million, equivalent to USD 0.022 per MHz per inhabitant.

3.1.2 Econometric analysis

Econometric analysis is used to estimate spectrum value taking account of factors such as demand conditions and industry structure. Econometric models are defined on the basis of a sample of auction results including the dependent variable (spectrum price) and numerous independent variables (band, bandwidth offered, timing of the auction in relation to development of the industry, licence period and geographical coverage, coverage obligations, characteristics of the auction, economic characteristics and structure of the industry).

The main drawback of econometric analysis concerns the availability of sufficient data (i.e. the number of auction cases to consider). As the statistical reliability of the results depends on having a large number of observations, this analysis is not very reliable if the number of cases involves fewer than 50 observations. Finally it is important to note that some of the independent variables may be defined in different ways by each country, and the statistical samples on which the analysis is based may thus lack consistency in terms of definitions.

3.1.3 Avoided costs models

As explained above, estimation of avoided costs is based on a calculation of the potential cost reduction (based on additional capacity or coverage) that would result from making additional spectrum available to operators. This model assumes that the operator must respond to demands for greater capacity in its network due to growth in the number of users and use of devices. Demand for increased network capacity may be met through:

- Improved technological efficiency (more Mbps/MHz)
- Better reuse of frequencies
- Enhancement of radio base infrastructure
- Combination of networks (for example, routing of cellular traffic via Wi-Fi sites)
- As a final option, acquisition of more spectrum.

The additional capital investment required for the first four options, without the possibility of acquiring more spectrum, is what is referred to as *avoided costs*. The advantage of the avoided costs model lies in the fact that, by being based directly on the specific characteristics of the market for which the spectrum price is being determined, the estimate is based on the immediate environment and specific context and does not depend on any extrapolation of spectrum price resulting from auctions in other countries. At the same time, as every competitor in the market can operate networks with specific characteristics, the spectrum value can be estimated for each operator. On the other hand, development of the model requires access to information on infrastructure and specific network operating costs for operators in the market for which the spectrum price is being determined.

3.1.4 Business case estimates

The basic assumption of this methodology is that an operator acquiring a licence in order to offer a telecommunication service would never pay more than the net present value (NPV) of the discounted cash flows generated by exploiting the licence. The aim is to estimate the expected profitability derived from acquisition of the spectrum. This model is particularly suited to the case of new entrants in the mobile market. Calculation of the discounted cash flow value requires an estimate of revenues based on the number of expected new subscribers, revenue per subscriber, and business operating costs.

This calculation is based on certain assumptions. First, that the spectrum is a cost-free input in the mobile operator's production operation. The price to be paid for spectrum thus cannot exceed the net value of the discounted cash flows generated by the acquisition of that spectrum. Secondly, the model assumes that all profitability is the result of acquiring the spectrum, when in reality a proportion of the profitability should be attributed to other factors such as the brand power associated with the purchaser.

3.1.5 Opportunity cost estimates

Opportunity cost is defined as the value of a commodity when it is used in the most advantageous alternative. In the case of spectrum, it means the alternative value that is foregone when a portion of radio spectrum is assigned to a specific use.

Opportunity cost estimates are used to determine the price of spectrum for different mobile cellular telecommunication services (for example, private mobile network services, satellite earth stations and microwave links). In such cases, the objective is to determine annual fees for using the spectrum in conditions of potential spectrum congestion. The goal in determining an annual fee is thus spectrum efficiency.

In these cases information on spectrum auctions is non-existent and comparable cases are thus not available. The valuation methods in such cases are thus similar to the avoided costs or business case models.

3.1.6 Integration of spectrum valuation methodologies

The starting point for determining spectrum value is a determination of the auction reserve price. This is the minimum price for which the seller is disposed to sell a commodity or service. Calculation of the reserve price, also regarded as the indifference point, is based on the avoided costs methodology. This assumes that an operator considering acquisition of a licence should not pay less that the cost involved in other ways of meeting the demand created by an increase in network traffic.

Having fixed the reserve price based on the avoided costs model, estimates of the maximum price should not exceed the net present value of the cash flows to be generated through access to the new spectrum. Having determined the two extremes of the price range, the value to be generated by an auction would be situated between those two extreme points. Nevertheless analysis of comparable results could generate a result outside the extremes of the price range, depending on the specific conditions in the country where the auction takes place (or the "winner's curse" effect).

It should be noted in conclusion that as regards spectrum valuation methods, the business case and opportunity cost models are extremely difficult for a regulatory authority to deploy owing to the high degree of information asymmetry. Despite the difficulty, however, it is advisable for regulators to build limited simulation models and compare them with comparable databases. Simulation models that introduce commercial and strategic variables enable us to capture important geographical specificities in integrated multinational markets.

In the case of Latin America, for example, where the mobile market has attained regional dimensions, the value of licences for multinational operators may be higher than can be inferred through extrapolation from auctions in national markets. For example, the value of additional spectrum for an operator already present in most adjacent geographical markets may be much higher than for a new entrant in the region. This appears to be the case in the recent 3G and 4G frequency auction in Argentina, where the estimated economic base was USD 1 966 million and the total bid was USD 2 233 million. At the same time an operator with a significant position in industrialized markets that has adopted a continental expansion strategy may be inclined to pay more for a licence, enabling the operator to become fully established in the region.

3.2 Estimating economic value of unlicensed spectrum (common use bands)

When the difficulty of providing sufficient spectrum restricts or distorts competition, or hinders development of radio spectrum resources, spectrum management may include applying economic factors to valuate alternative allocations. Section 5.2 sets out in detail the analysis of the alternative economic impact of allocation scenarios derived from the digital dividend. It also describes a methodology for estimating the economic value of common-use bands. This is of particular relevance in the context of alternative allocation of spectrum between general licences or licences exclusive to cellular operators.

As shown in Table 3 in section 2.3.1, certain frequency bands are assigned generally, without any requirement for a specific licence. Estimating their economic value is important inasmuch as spectrum management measures may result in additional bands being reallocated for common use, thus ceasing to be available for auction for exclusive use. While the economic value of bands allocated on an exclusive basis may be determined using methodologies such as those described in previous sections, valuation of a common-use licence calls for other methodologies. For this, it is necessary to ascertain the potential economic contribution of general licences in four areas:

- **Complementary value**: the value contributed by the general licence as a complement to other exclusive technologies. For example, Wi-Fi sites, which operate under common licences, can be used to complement cellular networks by routing traffic, thus potentially reducing capital investment on networks (see section 2.3.5 on combining networks).
- **Value of alternative technologies**: common licences can provide the platform required to develop new technologies to replace existing ones, increasing the range of options available to consumers. For example, these licences have facilitated the launch of video communication platforms such as WebEx or Skype, which offer possibilities for communication at prices that are more affordable for consumers.
- **Value of alternative business models**: as introducing new business models operating under common licences does not require prior authorization for operators holding an exclusive licence, development can be more dynamic.[40] There is no need for rent- or subsidy- sharing mechanisms, or modes of using frequencies beyond the requirement that the new business model comply with pre-established rules for common-use licences. All this speeds up the introduction of new applications, such as telemetry systems, security alarms and wireless video systems (all of which operate under common-use licences.
- **Value of expanding communication systems**: Wi-Fi technology allows the establishment of local telecommunication operators in isolated communities, thereby addressing a potential market failure. For example, in the United States some 3.2 million households are covered solely by operators referred to as *Wireless Information Service Providers* (WISPs) operating under common-use licences.

The combination of these four aspects of value creation enables us to calculate the contribution to GDP (in terms of new business) and create a consumer surplus (through lower prices for access to

[40] See Milgrom, P., Levin, J., and Eilat, A. (2011). *The case for unlicensed spectrum*. Stanford Institute for Economic Policy Research Discussion Paper No. 10-036.

communications) and producer surplus (derived from the reduction in capital investment in networks resulting from traffic routing measures).

3.3 International examples of spectrum valuation

As recommended in section 4.1, NRAs tend to use more than one technology to ascertain the value of spectrum with a view to an auction. The most important objective in calculating the spectrum value is to determine the reserve price, although some methodologies are also used by auction participants to determine bids. This section sets out examples of methodologies used in different cases.

3.3.1 Setting the reserve price in the auction of the 800 MHz and 2.5 GHz bands in the United Kingdom (2013)

In order to determine the reserve price, the regulator Ofcom commissioned a study using three methodologies: comparable results (benchmarking); business case estimates; and avoided costs. Comparable results were selected on the basis of auctions of the 800 MHz, 1800 MHz and 2.5 GHz bands on the continent of Europe. Although the selected cases were compiled on the basis of experience in Europe, they were adjusted to ensure results comparable with the British context. For the business case calculation, analysts assumed the value that different combinations of bands would have for different auction participants (for example, existing operators, new entrants, and wholesale operators). The major obstacle in the business case estimate was the lack of adequate information on the commercial and technology plans of different auction participants. This required many assumptions, which introduced a high level of uncertainty in the estimates. Finally, the avoided costs model was based on an analysis of three traffic growth scenarios, to obtain an estimate of the likely avoided costs if an auction participant acquires the licence for one of the bands.

3.3.2 Determining the price of licence renewal in the 850 MHz and 1 800 MHz bands in Australia

The price for renewing licences in the 850 MHz and 1 800 MHz bands in Australia was based on an estimate of the overall risk represented for operators by loss of the licence. Risk factors considered included the risk of losing the licence (which would result in costs of migrating users to other bands), the risk of the licence going to a new entrant in the market (leading to more intense competition), and uncertainty as regards future access to the spectrum. These factors suggested that, in order to recognize the risk of losing a licence at the time of renewal, the value in terms of avoided costs should be increased by between 25 and 50 per cent.

3.3.3 Setting the spectrum base price in El Salvador

Under the terms of the Regulations of the Telecommunications Law of El Salvador, the value of the spectrum base price is calculated using a pre-established formula:

Pbe = AB * PUBE * Pac

where:

Pbe:Spectrum base price

AB: bandwidth to be auctioned

PUBE: Unit price of spectrum per MHz per inhabitant

Pac: Population to be covered

The unit price of spectrum per MHz per inhabitant is calculated in January each year. For 2015, it was USD 0.018898 per MHz per inhabitant. It can be increased at the operator's discretion up to ten times if the frequencies in question are scarce or of major public importance (SIGET, 2015).

3.3.4 Setting a base price for acquiring a spectrum licence in Panama

The calculation is based on the price offered per MHz for acquisition of spectrum in Panama in May 2008, adjusted for variations in the Consumer Price Index for all Urban Consumers (CPI-U) in the United States at the time of acquiring the spectrum. At the present time two new mobile operators have entered the market (ASEP, 2015).

3.4 Economic and social benefit

In addition to the operator's economic aims, radio spectrum has value in terms of economic and social impact. Methods of estimating economic and social benefit offer a way of calculating the contribution to the wider economy of using radio telecommunications in terms of the impact on GDP and employment, and to calculate the consumer and producer surpluses. These methods can be used to calculate the economic benefits of providing a single end-user service; alternatively, the economic benefits of each service can be added together in order to estimate the total economic benefits produced by a country's radio communications.[41]

The following example concerns the possible deployment of networks offering mobile broadband services in Latin America. Mobile broadband (adoption of third and fourth-generation wireless devices) represents the most convenient technology for providing Internet access for most of the population in emerging regions. In Latin America, average take up of mobile broadband is 32.1 per cent (see Table 9).

Table 9. Latin America: Mobile broadband penetration (percentage of population) (2009-2013)

Country	2009	2010	2011	2012	2013
Argentina	0.50	1.89	3.67	8.41	19.28
Bolivia	0.13	0.53	3.02	7.62	14.26
Brazil	2.93	8.63	19.54	32.77	55.33
Chile	3.32	7.49	14.90	24.49	31.86
Colombia	1.35	2.39	4.61	8.62	16.70
Costa Rica	0.17	2.91	11.79	29.05	52.01
Dominican Republic	1.00	1.36	5.51	13.59	24.37
Ecuador	2.21	3.69	7.26	8.56	15.86
El Salvador	0.98	2.22	3.97	7.55	14.67
Guatemala	0.91	1.97	3.12	6.24	13.21
Honduras	0.66	1.20	1.86	3.97	7.00
Mexico	1.93	6.43	11.45	17.88	27.54

[41] See ITU-R report SM.2012-4 (06/2014), Economic aspects of spectrum management, p. 31.

Country	2009	2010	2011	2012	2013
Nicaragua	0.17	0.71	3.34	8.29	16.47
Panama	0.98	1.71	5.51	13.56	22.08
Paraguay	0.54	1.50	2.32	4.99	10.02
Peru	0.26	0.92	4.08	12.26	24.17
Trinidad & Tobago	0.00	0.00	0.00	0.03	0.14
Uruguay	3.74	10.60	17.68	28.29	42.92
Venezuela	11.81	16.04	20.81	28.07	32.31
Weighted total	2.31	5.77	11.58	19.41	32.10

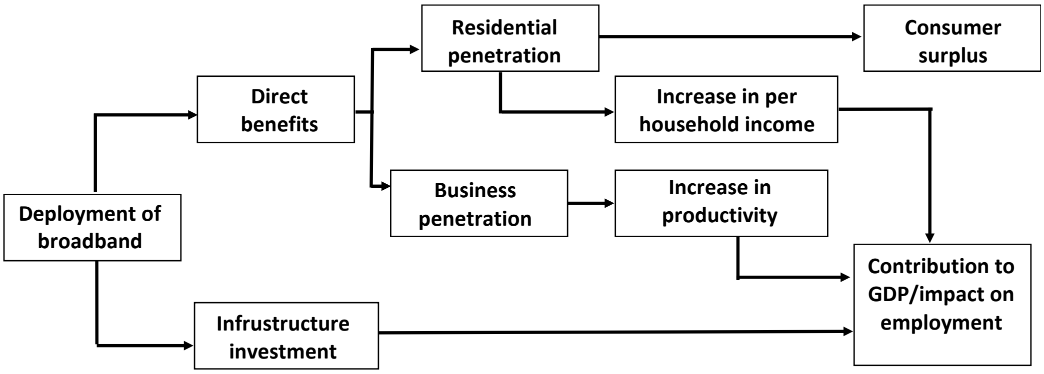
Source: GSMA Intelligence

Certain countries in the region have already exceeded or are close to attaining a penetration rate of 50 per cent of private individuals (Brazil, Costa Rica, and Uruguay), while others, given the high levels of growth, will achieve 50 per cent within two years (Argentina, Bolivia, Chile, Colombia, Dominican Republic, El Salvador, Guatemala, Mexico, Nicaragua, Panama, Peru, and Venezuela) or three years (Ecuador, Paraguay).

The greatly increased penetration of mobile broadband is the result of many different trends. First, mobile broadband is a technology especially well-suited for Internet access in conditions of mobility. Secondly, third- and fourth-generation technologies (LTE) result in greater efficiency in radio spectrum use, which means that operators are particularly interested in promoting moves to replace 2G systems with 3G or 4G. Third, mobile broadband is especially well-suited to meet the needs of population segments for whom fixed broadband remains inaccessible. The almost universal trend towards high penetration rates reflects the position of broadband both as a complement to fixed technology (in the business sector and medium- to upper-income levels of the population), and as a substitute for fixed broadband for less well-off sectors.

The importance of mobile broadband as an appropriate technology for increasing Internet access is reflected in its economic impact. The economic contribution of broadband as a common-use technology is made clear by numerous effects (see Figure 5). The first is the result of building telecommunication networks and takes the same form as any infrastructure project: deployment of broadband creates employment and has an impact on the economy as a whole through multiplier effects. The second impact concerns the spill-over effect on the overall economic system, which affects both companies and residential consumers. Use of broadband by the productive sector boosts productivity, which contributes to GDP growth; at the same time, its adoption by families boosts real household incomes, leading to a reduction in poverty and promoting economic growth.

Figure 5: Economic contribution of broadband



Source: Compiled by author.

Apart from these effects, residential users with broadband obtain benefits in terms of the consumer surplus, defined as the difference between the consumer's willingness to pay for a service and the market price. This effect, although not included in the calculation of GDP, is important in that it represents benefits in terms of access to information, training and public services.

The first analysis of broadband's economic impact in Latin America was carried out by Katz (2010) on the basis of a sample of countries.[42] Owing to the absence of time series data, the analysis was based on the ordinary least squares methodology applied to an aggregated data sample for 2004 and 2009. Subject to the proviso that the number of observations made was limited, the results indicated that, taking account of statistical data on levels of education and initial GDP per capita, a growth of 1 per cent in broadband penetration contributes 0.0158 per cent to GDP growth. In 2011, greater availability of disaggregated data made it possible to conduct studies at the national level. The first of these was conducted by Colombia using departmental data between 2006 and 2010 (Katz and Callorda, 2011). This study analysed the impact of fixed broadband on GDP growth in a geographical department taking account of initial economic development, population growth and level of human capital (years of education). The model shows that an increase in broadband connections has a positive impact on GDP growth; if connections grow by 10 per cent, GDP will grow 0.037 per cent. The effect is less pronounced than with the model for the region as a whole, owing mainly to the fact that average broadband penetration in some emerging countries is lower than the Latin American average.

In addition to its impact on economic growth, broadband contributes to job creation, although the effects in this case are more complex. In the first place, increased penetration may boost productivity, which, in the short-term, may result in a net reduction in employment. This effect has been confirmed by the author for labour-intensive industrial sectors. Secondly, by integrating new sections of the population in the electronic access market, broadband contributes to the creation of new business through the effect of innovation, which results in new jobs. Lastly, it may promote outsourcing of certain company operations to third parties, resulting in the creation of jobs as outsourcing firms are established, although opportunities may also be lost if aspects of company operations are transferred to other parts of the world. In order to estimate the impact of broadband in Chile, a study was conducted using panel data based on fixed effects and considering the specific characteristics of each region within the country that impact on the labour market (industrial sectors, education levels). The model is based on a panel of quarterly data gathering together information for all regions (except the Metropolitan Region owing to a lack of quarterly data) from 2001 until the fourth quarter of 2009. According to the results of the model, a 10 per cent increase in broadband penetration in Chile boosts the employment rate by 0.018 percentage points. The main result is that the increased broadband penetration appears to be a significant factor in employment growth during the period in question.

[42] See ITU (2012). The impact of broadband on the economy, Geneva, available at https://www.itu.int/ITU-D/treg/broadband/ITU-BB-Reports_Impact-of-Broadband-on-the-Economy.pdf

A similar analysis was undertaken for Colombia. In this case, a model was created at the departmental level, relating growth in broadband connections to growth in employment, taking account of population growth and initial level of economic development. The model was initially applied to the entire country, with subsequent disaggregation by departments with high and low penetration. In these models the effect is significant at the national level and for all departments with low penetration; in departments with high penetration the coefficient is 24 per cent (see Table 10).

Table 10. Impact of growth in broadband penetration in terms of employment growth

	Total	Low penetration	High penetration
Growth in broadband access (%)	0.0003004 **	0.0002951 **	0.0006572
	(0.0001359)	(0.0001547)	(0.0005495)
Population growth (%)	0.0159829	-0.2538734	0.5937073 *
	(0.5114836)	(0.7899623)	(0.3761862)
GDP 2003 (million pesos)	0.0053431	-0.1084577	0.0003309
	(0.0077051)	(0.1308956)	(0.0090124)
R^2 adjusted	0.0110	0.0318	0.0338
Prob > F	0.0730	0.0321	0.4351
Number of observations	132	64	68
Note: ***, ** and * indicate significance levels 1%, 10% and 15%			

Source: Katz, R. and Callorda, F. *Medición del impacto del Plan Vive Digital en Colombia y la masificación de Internet*. Bogotá, Ministry of Information and Communication Technologies, 2011, p. 31.

In an analysis based on a structured model for the case of Ecuador, Katz and Callorda (2013) found that broadband contributed significantly to growth of Ecuadorian GDP between 2008 and 2012. The annual average contribution to GDP growth was estimated at 0.052 per cent for every 1 per cent of growth in penetration. The results set out in Table 10 show that there was an average increase in income for individuals of USD 25.76, or 7.48 per cent of the initial average income for the sample. Given that the introduction of broadband occurred over a period of two years between December 2009 and December 2011, this implies an annual increase in income of 3.67 per cent. This increase reflects not only the gains generated directly by use of broadband but also takes account of its impact on the labour market in terms of manpower required for deploying networks, new staff hired by service providers, and spill-over effects for society as a whole.

4 Principles of public and regulatory policy governing the assignment and use of the radio spectrum

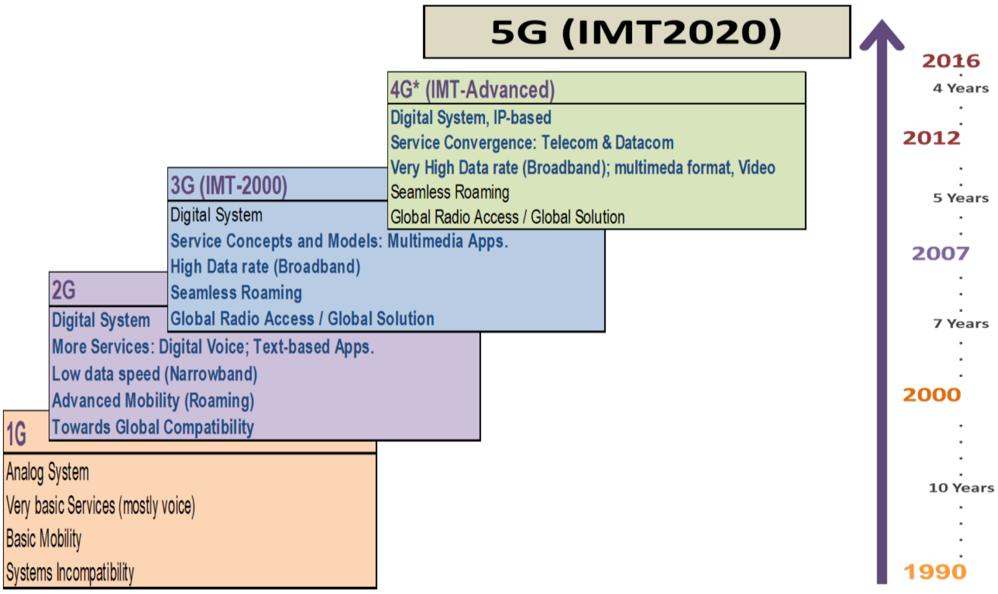
4.1 Demand for spectrum

Data traffic in Latin America is increasing significantly owing to a large extent to the emergence of mobile broadband. This is generating an ever-increasing need for spectrum. The region currently has a unique opportunity to address this situation by harnessing the “digital dividend”, as has already been done in the United States and some countries of the European Union.

Mobile telecommunications have achieved massive penetration levels on the Latin American continent, where the 123 per cent average in the fourth quarter of 2014 represents a level of uptake that is broadly similar to the rate observed in industrialized countries. Based on the current situation, the historical trend and a conservative estimation of expected saturation levels, mobile telephony penetration is expected to reach a regional average exceeding 140 per cent by 2020[43].

In parallel with the rapid adoption of mobile telecommunications, operators in Latin America have been migrating their networks from second (2G) to third (3G) generation technologies. In 2015, we have also been witnessing the beginnings of migration to 4G platforms, based primarily on the LTE standard. Migration to 3G technology is important inasmuch as terminals operating in accordance with such standards (for example, HSPA+) are better suited than fixed broadband technologies to providing broadband Internet access. This technology thus represents an adequate response to the needs of a market constrained by the still relatively high costs of computer purchase and limitations on fixed broadband deployment. The need to satisfy public demand while making more efficient use of the radio spectrum is such that we will be seeing most of the region's subscribers migrating to 3G platforms within the present decade. According to the author's forecasts for the rate of terminal substitution in Latin America, 46.2 per cent of the region's subscribers will be using 3G or 4G terminals by 2015. With the dramatic increase in subscribers using HSPA – and later LTE – technology, some countries of the region will be seeing 3G and 4G terminals making up the major part of the installed base. By 2020, for example, it is expected that 87 per cent of the installed base in Argentina, 73 per cent in Mexico and 76 per cent in Brazil will be 3G or 4G terminals[44]. Figure 6 illustrates the evolution of the different generations of mobile networks.

Figure 6: Evolution of mobile network technologies



Source: ITU/BDT Workshop on Guidelines on the policy and economic aspects of the assignment and use of the radio-frequency spectrum[45] (Nicaragua, 4 September 2015) – BR presentation.

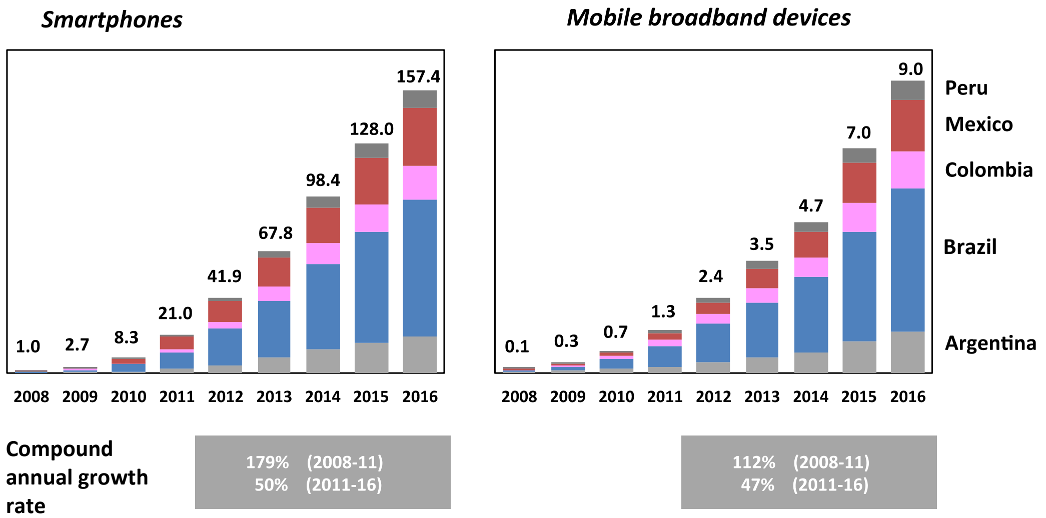
The migration to 3G terminals encompasses a significant trend: the adoption of smartphones. Such terminals have more advanced functionality than basic telephones, with interfaces and screen formats more geared to Internet access. The ease of broadband access they enable is reflected in the fact that smartphone users make more intensive use of their mobile line. While the smartphone installed

43 Source: GSMA Intelligence.
44 Katz, R., Flores-Roux, E. *Beneficios Económicos del Dividendo Digital para América Latina* [in Spanish]. London: GSMA, 2011
45 See Report ITU-R SM.2012-4, *Economic aspects of spectrum management*, p. 19.

base in Argentina, Brazil, Colombia, Mexico and Peru currently amounts to some 20.9 million (or 4.5 per cent of the total base), it is expected to increase at a compound annual growth rate of 50 per cent and to reach 157 million by 2016 (making 28 per cent of the installed base in that year). Another important consideration is that a significant share of the smartphone installed base will be substituted by tablets, although given their embryonic penetration within the region it is difficult to assign an accurate figure to that share.

To the uptake of smartphones we must add the number of laptop computers connected to the Internet through mobile broadband, which currently amounts to some 1.3 million in the above-mentioned five countries (a mere 1.5 per cent of the installed base). However, these peripherals are growing at an annual rate of 47 per cent, which will bring the installed base to a total of 9 million by 2016[46]. The combination of the trends discussed above, coupled with the deployment of "machine-to-machine" connections (the so-called "Internet of things"), is generating a dramatic increase in the amount of data traffic to be carried by mobile networks. While the monthly volume of data traffic in the aforementioned five countries amounted to 362 TB in 2008, by 2011 it had risen to 11 906 TB, and is expected to reach 180 214 TB in 2016, signifying a compound annual growth rate of 117 per cent[47] (Figure 7).

Figure 7: Growth in the installed base of traffic-generating terminals



Source: Telecom Advisory Services (2011)

To meet the growing need for network capacity, the mobile telecommunication industry requires access to additional radio spectrum. This being the case, the world radiocommunication conferences of the International Telecommunication Union (ITU) have been identifying a series of bands (see table below) for IMT (international mobile telecommunications), including the band 698-960 MHz ("700 MHz"), which includes the portion 698-806 MHz, known as the "digital dividend", the L-band (around 1 500 MHz) and the lower part of the C-ban (3.4-3.6 GHz). Table 11 summarizes the bands thus far identified for IMT (including, with blue shading, those most recently identified by WRC-15).

46 Katz, R., Flores-Roux, E., op. cit.

47 It is important to note that the need for broadband may vary between large and small countries at differing stages of development (Scheker, 2015).

Table 11. Bands identified for IMT (WRC-15)

Band (MHz)	Bandwidth (MHz)
450-470	20
470-608	38
614-698	84
698-960	262
1 427-1 452	25
1 452-1 492	40
1 492-1 518	26
1 710-2 025	315
2 110-2 200	90
2 300-2 400	100
2 500-2 690	190
3 300-3 400	100
3 400-3 600	200
3 600-3 700	100
4 800-4 990	190
15 Bands	**1 780**

Source: ITU 2015 World Radiocommunication Conference (2-27 November 2015, Geneva, Switzerland).

Up until WRC-12, eight bands totalling 1 177 MHz had been identified. WRC-15 then identified a further seven bands amounting to 603 MHz (an additional 51 per cent), for an overall total of 15 bands representing 1 780 MHz.

These identifications are beneficial not only in terms of the efficient accommodation of data traffic, but also, given the better signal propagation characteristics at 1 500 and 700 MHz, because they open up opportunities for the deployment of mobile telephony in rural areas, with the resulting positive social impact. In addition, the 700 MHz band enables improved indoor coverage in urban environments. This band is known as the "digital dividend".

In the latter part of 2013, the average amount of spectrum per Latin American country assigned to mobile telecommunications amounted to 270 MHz – far less than the 1 340 to 1 960 MHz that the region will, according to ITU estimates, be needing by 2020[48]. In this regard, the frequencies traditionally allocated to mobile telecommunications are not sufficient to accommodate the future growth of mobile broadband. This being the case, the ITU Member States identified, during WRC-15, additional spectrum to the tune of 51 per cent for IMT.

48 See studies carried out under agenda item 1.1 and by Working Party 5D. International Telecommunication Union. Report ITU-R M.2290-0 (12/2013), Future spectrum requirements estimate for terrestrial IMT. Report ITU-R M.2370. Furthermore, Coleago estimates that the spectrum requirements for Argentina, Brazil, Chile, Colombia and Mexico by 2020 will lie between 893 MHz (low-usage scenario for Chile) and 1 676 MHz (high-usage scenario for Brazil).

4.2 The digital dividend

The digital dividend is defined as the benefit generated by the digitization of television, which allows for reallocation of part of the spectrum in the 700 (698-906) MHz and 470-698 MHz bands from broadcasting (or other technologies) to mobile services[49]. In recent years, numerous countries in Latin America have already auctioned spectrum in the 700 MHz band (for example, Argentina, Brazil, Chile, Panama and Bolivia)[50]. In the case of Mexico, the band will be assigned to a public-private enterprise to enable it to offer wholesale services. At the same time, many countries are working to "clean up" the spectrum in this band (by reassigning the various types of operator currently using it), with a view to auctioning it within the mobile telecommunication industry.

Like the 700 MHz band, the band 470-698 MHz is being used by other services. In particular, frequencies between 608 and 614 MHz are allocated to radio astronomy services, while bands between 407 and 698 MHz are allocated to the broadcasting service.

Once digitization of the television signal began to enable more effective use of the radio spectrum, analysis of the economic, social and technological impacts took on major significance. Numerous studies have been conducted in different geographic contexts, mainly within Europe and Asia, resulting in key reports in countries such as France and Australia. It has to be mentioned, however, that although the results of the studies tend to be generally consistent in emphasizing the economic value of a change, which enables the digital dividend to be allocated and reassigned to mobile telephony, some essential differences are to be found in terms of approach and methodology. The aim of this chapter is to provide a summary presentation of the different methodologies and conclusions of the main studies and thus to create a theoretical referent that can be used to define a methodology for analysing the economic impact of using spectrum in the 700 MHz band, or in the band below 700 MHz (470-698 MHz). The first is known as the digital dividend, while the second is referred to as Digital Dividend 2 in Latin America.

In general terms, the various studies carried out to date can be divided into four categories:

- **Estimation of the private economic value of scenarios involving changes in spectrum allocation**: This methodology estimates the added value to be generated by alternative spectrum usage assignment scenarios – mobile broadband or broadcasting. It is an approach that does not calculate the external or public economic value derived from the indirect contribution to GDP growth or creation of employment.
- **Estimation of the social and economic impact of spectrum assignment scenarios**: By contrast with the previous approach, this methodology defines two alternative usage scenarios for the 700 MHz band – assignment to broadcasting or to mobile telecommunications – and measures the comparative economic impact of the two scenarios (for example, direct and indirect contribution to GDP, direct and indirect job creation, fiscal contribution).
- **Economic assessment of the assignment of spectrum to mobile telecommunications**: This approach analyses two alternative scenarios for satisfying mobile telephony's growing demand for spectrum – use of the bands previously assigned at 800 MHz and 1 900 MHz, or assignment of the 700 MHz band – and measures the difference in terms of the investment required by each alternative in order to arrive at a single measurement (value to society in terms of wealth created) for each of the scenarios and subsequently to conduct a number of relevant comparisons. Assuming a high level of complexity, some studies set out multiple scenarios

[49] Report ITU-R BT.2140-8 (February 2015), Transition from analogue to digital terrestrial broadcasting (www.itu.int/pub/R-REP-BT.2140-8-2015) and Report ITU-R SM.2353-0 (June 2015), The challenges and opportunities for spectrum management resulting from the transition to digital terrestrial television in the UHF bands (www.itu.int/pub/R-REP-SM.2353-2015).

[50] See Alden, J. (2011), Exploring the value and economic valuation of spectrum: GSR Advanced Copy. Geneva, International Telecommunication Union, pp. 24-26.

involving demand for audiovisual and telecommunication services and assess the economic value of different spectrum assignment alternatives.

- **Simulation of the social value of assigning spectrum to mobile telecommunications**: This type of analysis lays the emphasis on estimating the benefit to consumers in terms of social value.

A number of the studies carried out and conclusions reached under each of the above four categories are presented in the following sections.

4.2.1 Estimation of the private economic value of scenarios involving changes in spectrum allocation

The main objective of studies based on this methodology has been to identify optimal public policies for assigning a portion of the spectrum in the 700 MHz band to mobile telecommunications. Carried out at a time when there was a degree of uncertainty regarding the expected growth rate of mobile data traffic, such studies focus on the formulation of scenarios for growth of the sector. However, given the incipient state of research into the economic impact and externalities of broadband at the time when those studies were carried out, the studies tend to point to the potential impact without quantifying it.

Study commissioned by ARCEP (the French telecommunication regulator)

In 2008, the firms Analysys Mason and Hogan & Hartson carried out, for the case of France, a study of two spectrum assignment scenarios for spectrum released as a result of the digital dividend. The first scenario allocates the entire spectrum to the transmission of television signals, while the second looks at spectrum sharing, with the mobile industry receiving the sub-band 790-862 MHz and the remainder being assigned to television. The comparative analysis of the two scenarios was performed on the basis of three dimensions:

- Microeconomic analysis: The spectrum-sharing scenario generates a higher added value than the scenario involving the assignment of spectrum solely to television, and is estimated at EUR 25 000 million between 2012 and 2024.
- Macroeconomic analysis: The spectrum-sharing scenario helps to grow France’s GDP by EUR 7 100 million, as compared to EUR 2 300 million for the assignment of spectrum solely to television. This analysis does not include the productivity gains resulting from the introduction of mobile broadband services in the sharing scenario.
- Externalities analysis: This module is not evaluated quantitatively, despite concluding that the accumulated externalities are greater in the case of spectrum sharing.

Study commissioned by the European Commission

In 2009, the firms Analysys Mason, DotEcon and Hogan & Hartson carried out a study commissioned by the European Commission to assess the relative benefits deriving from the reassignment of spectrum released by the digital dividend in the countries of the European Union. The approach taken by this study consisted in estimating the “private value” (direct benefit received by individuals from the consumption of a given service minus the cost of its delivery; in other words, the difference between the consumer and producer surpluses) generated according to various spectrum demand and supply scenarios.

The spectrum supply scenarios considered essentially come down to two types: a scenario involving the temporary sharing of sub-bands, and another involving sole assignment to mobile broadband. The demand scenarios include six alternatives combining high or low demand for audiovisual and mobile broadband services. The analysis involves comparing the values generated by the spectrum assignment alternatives with the different demand growth scenarios and identifying which scenario represents the optimum supply in terms of the creation of value to satisfy the demand. Thus, in a scenario where there is high demand for mobile broadband and low growth in the demand for digital terrestrial television services, the optimum alternative for creating value is the temporary sharing of sub-bands, which generates EUR 61 000 million in economic benefit. The study concludes that there is a sound argument in favour of allocating and assigning at least one sub-band between 790 and 862 MHz to mobile broadband in order to satisfy the demand for this type of service.

Given that the study focuses solely on "private" value, to the consequent exclusion of any public value resulting from spillover effects into other sectors of the economy, the authors have to use a multiplier calculated in a study by Ofcom, the United Kingdom regulator, which estimates the external public value as being between 5 and 15 per cent of the private value. On the basis of this factor, the authors conclude that the total value of the digital dividend for the European Union lies between EUR 150 000 and 700 000 million (discounted NPV at 15 years).

Study commissioned by the International Telecommunication Union [51]

This study compiles the 2011 situation in various countries of the world as regards spectrum reallocation resulting from the digital dividend. It reviews the experience of countries in each region of the world, detailing the cases of Latin American countries in terms of the procedures followed for spectrum reallocation and auctioning in the 700 MHz band.

Estimation of the social and economic impact of alternative spectrum allocation scenarios

These studies focus essentially on an area that is partially sidelined by the studies described above, namely the impact of externalities. The metrics calculated on the basis of benchmarks or quantitative models focus on the external economic impact to be derived as a result of alternative spectrum allocation and assignment scenarios: contribution to GDP growth, increased productivity and the creation of employment are some of the indicators calculated in these studies.

Study commissioned by Deutsche Telekom for the European Union

In one of the first studies carried out to evaluate the digital dividend, Deutsche Telekom engaged the firm SCF Associates to conduct a study focusing on the European Union. The study defines two scenarios involving assignment of the 800 MHz band, with the major part of it being allocated to television or mobile telephony. Both scenarios presuppose the allocation of 15 per cent of the band for other uses, including military applications.

The study is based on metrics generated in the course of previous research in areas such as the impact of broadband on GDP, generation of direct and indirect employment and consumer surplus. At the same time, it models the impact of the scenarios in areas such as revenue and expenditure on the purchase of infrastructure. The authors conclude that the direct economic effects within the European Union (services, revenue, etc.) for mobile telephony operators amount to an estimated EUR 208 000 million, as against EUR 43 000 million for television. Expenditure within the provider ecosystem amounts to EUR 87 000 million for mobile telephony and EUR 30 000 for television. The consumer and producer surplus is estimated at EUR 165 000 million in the mobile industry and EUR 95 000 for television. Finally, the mobile sector would generate 2.3 million jobs, while 1.8 million jobs would be created on the television side.

Study commissioned by Telenor, LM Ericsson and GSMA for Asia

In 2010, the firm Boston Consulting Group carried out, for the Asia region, an analysis of the social and economic impact of reallocating the 700 MHz band to mobile telecommunications as compared to its existing allocation to broadcasting. The analysis was focused on four countries – the Republic of Korea, Malaysia, India and Indonesia – and its conclusions were extended to the rest of the continent. Its purpose was to estimate the increase in the uptake of broadband resulting from the reallocation of

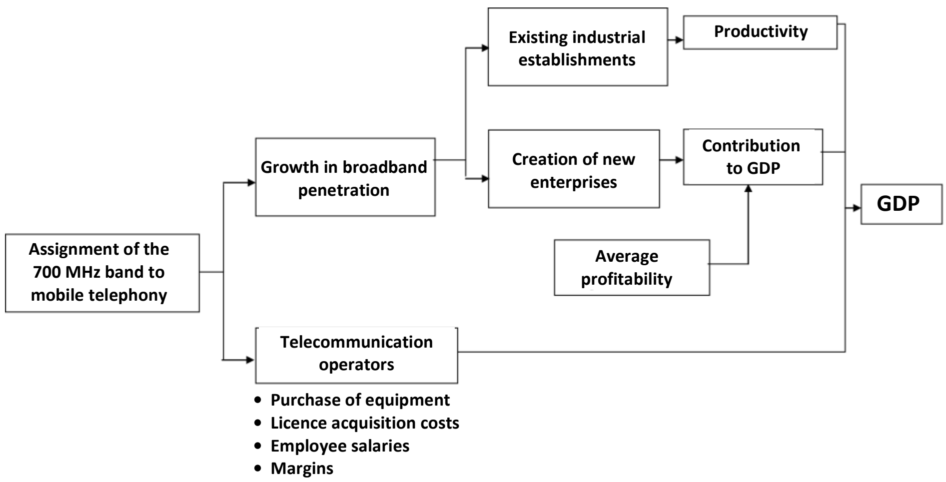
[51] Alden, J. (2011), Exploring the value and economic valuation of spectrum: GSR Advanced Copy. Geneva. International Telecommunication Union (ITU/BDT).

the 700 MHz band and the consequent contribution to GDP growth, increased productivity, creation of jobs and other macro-economic indicators.

The initial premise for this study was as follows: allocation of the band 698-806 MHz to mobile telephony for the provision of broadband reduces the investment and operating costs of service providers, which reflect the producer surplus in prices. This drop in prices drives an increase in broadband penetration, impacting the macroeconomic variables (productivity, GDP, employment, tax revenues) and contributing to the creation of social benefits such as improved access to education and health services.

Assuming a fall of between 6 and 10 per cent in mobile broadband prices thanks to the handing-on of part of the producer surplus, the study estimates that mobile broadband penetration will increase, beyond the projected rates, by 14 per cent in Korea, 23 per cent in Malaysia, 22 per cent in Indonesia and 21 per cent in India, all of which translates into a significant economic contribution. For example, using a methodology, which, at the macroeconomic level, disaggregates the impact of broadband on the productivity of six economic sectors, the study estimates the impact of the technology on total factor productivity and the consequent contribution to GDP. In another impact area, using correlation coefficients between broadband penetration and the creation of new enterprises, the study calculates the contribution of incremental mobile broadband penetration to the creation of new enterprises, for the most part within the ICT ecosystem (see Figure 8).

Figure 8: Structure of the model for the economic and social impact of the digital dividend in Asia



Source: Adapted from the study by Boston Consulting Group (BCG)

Comparing the GDP contribution of a scenario in which the digital dividend is reassigned to mobile telephony with one in which it remains with broadcasting, the study concludes that the contribution to Asia's aggregate GDP of the first scenario amounts to USD 729 000 million, while that of the second is USD 71 000 million. Finally, while not estimating them quantitatively, the study mentions the social impacts on health, education and social cohesion.

4.2.2 Economic appraisal of allocating spectrum to mobile telecommunications

Although these studies address matters such as benefits to consumers (measured in terms of consumer surplus), their emphasis is on the analysis of cost-benefit for the mobile industry as compared to television in the context of allocation of the digital dividend. Such an analysis calls for the construction of detailed models of mobile broadband demand and of the growth of traffic over networks configured with and without access to the 700 MHz band.

Study commissioned by Ericsson, Nokia, Orange, Telefónica and Vodafone for the European Union

This study, carried out in the first half of 2008 by the firm Spectrum Value Partners, analyses the economic impact within the European Union of the possible allocation to mobile telephony of a portion of the UHF band. Since it focuses on a cost-benefit analysis of spectrum allocation, its point of departure is the elaboration of traffic demand scenarios, particularly where data transmission is concerned. Based on assumptions with respect to terminal penetration and use, the model generates an estimation of the capacity to be accommodated by the mobile network. Given the current uncertainty as to the rate of growth of the demand for data traffic, the study elaborates three scenarios. On the basis of these three traffic growth scenarios, it estimates the economic impact of two alternatives designed to satisfy the demand: with or without access to the digital dividend. The cost-benefit analysis of both scenarios is structured with reference to four dimensions:

- Producer surplus, defined as the benefits obtained thanks to a fall in production prices and passed on to the consumer in the form of lower prices.
- Consumer surplus, defined as the difference between willingness to pay and the prices charged.
- Indirect benefits such as, for example, the impact of growth on the ICT ecosystem.
- Externalities, seen as growth in employment, productivity gains and social benefits. In this regard, the study bases itself on the metrics calculated by Ofcom (15 per cent of the producer and consumer value), as well as on another study (SCF Associates) which calculates direct and indirect economic benefits.

The cost-benefit value is the sum of these effects within a scenario involving use of the 800 MHz band as compared with its non-allocation to mobile telephony. The study constructs numerous sensitivities according to the different portions of spectrum to be allocated. For example, were mobile telephony to receive 80 MHz, this would result in a value for Europe as a whole of EUR 111 500 million in terms of net present value.

Study commissioned by the Australian Mobile Telecommunications Association

In 2009, the firms Spectrum Value Partners and Venture Consulting completed a study, commissioned by the Australian Mobile Telecommunications Association, to evaluate the digital dividend for Australia. The methodology used was broadly consistent with that used by Value Partners for the study it conducted for the European Union.

The study concluded that the allocation of a portion of spectrum in the UHF band (with variations according to geography, but reaching 120 MHz in rural areas) generates a benefit in the order of USD 7 000 to 10 000 million, depending on the demand growth scenario. Given the particular features of Australia's geography, the study focused on the benefit for rural areas, where broadband provision will be essentially wireless, with maximum economic benefit thus being obtained through assignment to mobile telephony at 140 MHz.

4.2.3 Simulation of the social value of assigning spectrum to mobile telecommunications

A simulation exercise conducted by Avanzini and Muñoz (2010) reflects the high social value that an assignment of 108 MHz to mobile broadband would have in Latin America. To calculate this value, the authors re-estimated the Hazlett and Muñoz (2009a) model on the basis of the digital dividend being assigned to the provision of advanced digital mobile services. It was assumed that the digital dividend generated in each Latin American country was 108 MHz, located in the upper segment of the UHF band, and that its reassignment, at least partially, would not require analogue switch-off.

This study assumes that the spectrum will be released in advance of the analogue switch-off, given that the bands remaining in the hands of open television operators are sufficient for the simultaneous transmission of analogue and digital signals. In line with this assumption, the gross social value is also a reference for the net social value, without it being necessary to make an adjustment for the cost of the decoders needed for the television reassignment. Owing to database limitations, the social value was estimated for only nine countries of the region, producing an average social value for the resource of USD 408.3 per capita for assignment of 108 MHz of the UHF band, with Brazil obtaining the least value (USD 129.8 per capita) and Venezuela potentially generating the highest value within the region (USD 1 257.1 per capita) (see Table 12).

Table 12. Calculation of the social value of reassigning the 700 MHz band to mobile telephony

Country	Population (millions)	Var. consumer surplus (USD millions)	Var. well-being (USD millions)	Var. well-being per capita (USD/capita)	Value MHz USD/ MHz pop.
Argentina	40.13	11 943	24 744	616.6	5.7
Brazil	191.48	11 936	24 862	129.8	1.2
Chile	16.98	3 577	6 883	405.4	3.8
Colombia	49.04	3 320	6 912	140.9	1.3
Ecuador	14.12	2 404	5 015	355.2	3.3
Mexico	107.75	14 338	28 820	276.8	2.6
Peru	29.10	2 799	5 826	200.2	1.9
Uruguay	3.35	473	982	293.1	2.7
Venezuela	28.61	17 343	35 966	1.257.1	11.6

Source: Avanzini and Muñoz (2010)

The authors concluded that this high value in Latin America could be attributable to the fact that mobile operators are very restricted in terms of the spectrum resource.

4.2.4 Conclusion from analysis of the studies conducted to date

To begin with, there is a noteworthy consistency between the various studies conducted to determine the range of economic benefits that can be generated by assigning a portion of UHF spectrum to the mobile industry (see Table 13).

Table 13. Comparative evaluation of the value of assigning spectrum

	Indicator	Television (millions)	Telephony-mobile broadband (millions)	Ratio
European Union (Value Partners)	NPV over 20 years	EUR 750 000-850 000	EUR 813 00-1 015 000	1.14
Asia (BCG)	Contribution to GDP	USD 54 000	USD 502 000	9.3
	Tax revenue	USD 20 000	USD 76 000	3.8
	New jobs	100 000 jobs	2 200 000 jobs	22

	Indicator	Television (millions)	Telephony-mobile broadband (millions)	Ratio
European Union (SCF)	Revenue generated	EUR 43 000 million	EUR 208 000	4.8
	Expenditure on ecosystem	EUR 30 000 million	EUR 87 000	2.9
	Contribution to GDP	0.0%	0.6%	
	Direct jobs	400 000	500.000	1.25
	Indirect jobs	1.8 million	2.3 million	1.3

Source: Author's compilation

From an analysis of the studies carried out to date, we see a certain level of methodological consistency combined with a variety of approaches and degrees of emphasis. Broadly speaking, the studies conducted in 2008 tend to develop models for forecasting the demand for data traffic (for example, the study performed by Spectrum Value Partners to examine the situation in Europe). The need to develop traffic models is now becoming less important as we begin to see signals within the market of an explosive trend towards traffic growth.

Beyond this similarity, the levels of emphasis in the approaches taken in the different studies vary substantially (see Table 14).

Table 14. Levels of analysis of the digital dividend

	France (ARCEP)	Europe (CE)	Europe (Operators and manufacturers)	Asia (Ericsson, Telenor, GSMA)	Australia (AMTA)	Europe (Deutsche Telekom)
Authors	Analysys Mason, Hogan & Hartson	Analysys Mason, Hogan & Hartson	Spectrum Value Partners	Boston Consulting Group	Venture Consulting, Spectrum Value Partners	SCF Associates
Traffic model		**Yes** (qualitative scenarios)	**Yes** (traffic model)	**No**	**Yes** (traffic model)	**No**
Cost-benefit for the mobile industry (with or without UHF)		**No**	**Yes** (constructing a network model)	**No**	**Yes** (constructing a network model)	**No**
Producer surplus		**Yes**	**Yes**	**No** (involves cost-reduction benchmarks)	**Yes**	
Consumer surplus			**Yes** (calculated on mobile broadband price reductions)	**No** (uses price reduction to estimate incremental penetration)	**Yes** (involves international benchmarks for willingness to pay)	**Yes** (uses benchmarks)

	France (ARCEP)	Europe (CE)	Europe (Operators and manufacturers)	Asia (Ericsson, Telenor, GSMA)	Australia (AMTA)	Europe (Deutsche Telekom)
Externalities (employment, GDP growth, etc.)		**Yes** (uses benchmarks)	**Yes** (uses benchmarks)	**Yes** (develops disaggregated models)	**Yes** (uses benchmarks)	**Yes** (uses benchmarks)

Source: Author's compilation

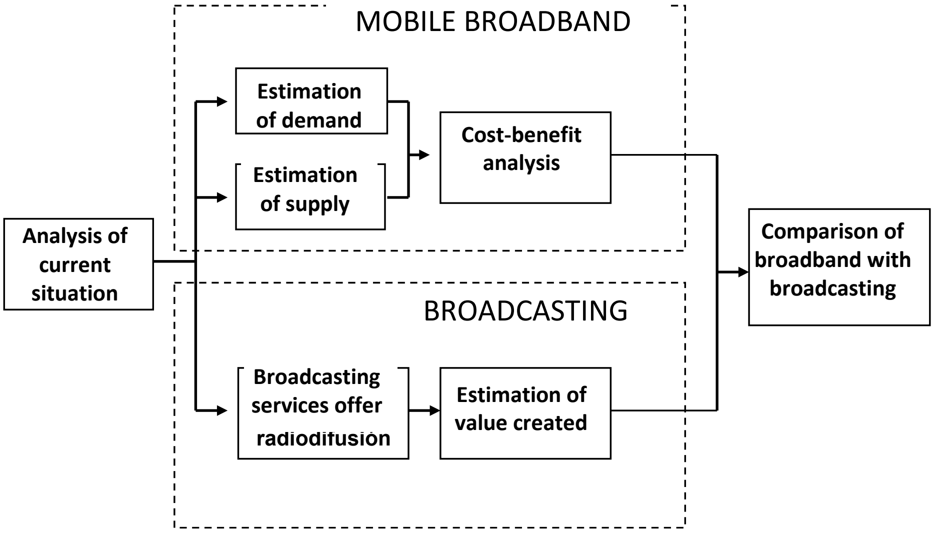
On 18 November 2015, France auctioned the digital dividend, obtaining revenue in the amount of EUR 2 796 million (approximately USD 2 991.72). The broadband thus auctioned was 2 x 30 = 60 MHz, the revenue per MHz amounting to USD 49 862 and the revenue per MHz and population being USD 0.752. An additional round was held in order to define the order of eligibility of the specific channels, thereby generating an increase in these values.

4.3 Methodology for valuing the digital dividend

The present study differs from the previous ones in two respects. First, it applies very comprehensively the majority of the methodologies that the above-mentioned studies apply partially. This section presents an integrated methodology for valuing the digital dividend that can be applied both in the 700 MHz band and in the 470-698 MHz band.

Insofar as quantification of the economic value of spectrum in these bands has to be carried out comparatively with respect to alternative allocation scenarios, the analysis should generate results both for mobile telecommunications and for the original allocation (which, in the case of the 700 MHz band, for example, would be broadcasting- see Figure 9).

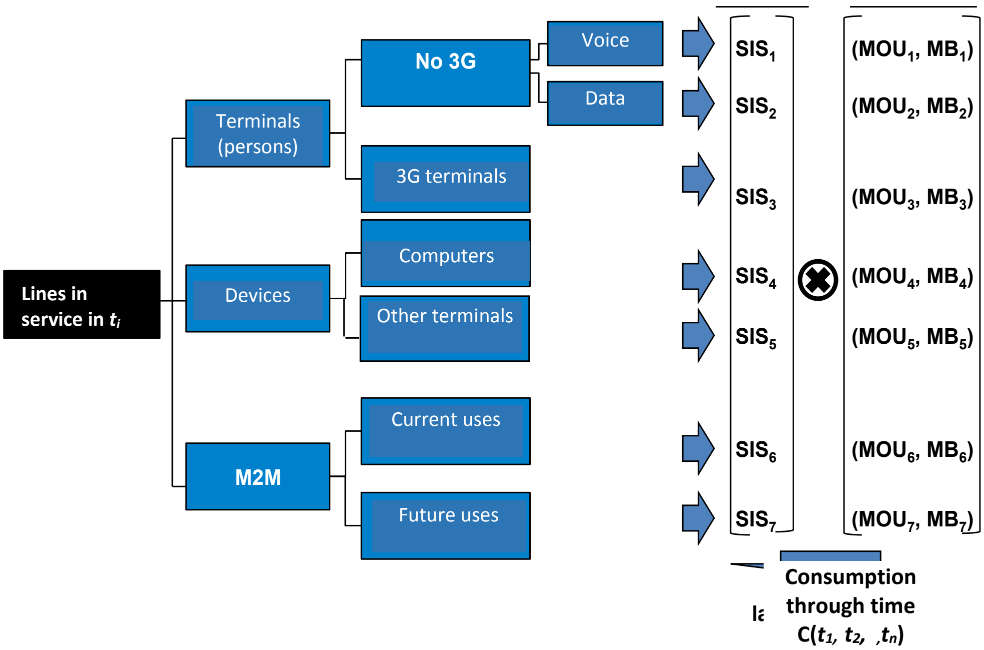
Figure 9: Basic theoretical framework of the valuation methodology



Source: Author

Estimating the economic value of mobile telecommunications begins with forecasting the growth in data traffic. This calls for the construction of a demand model based on the number of users, average use per application and required volume per application (see Figure 10).

Figure 10: Structure of the demand model



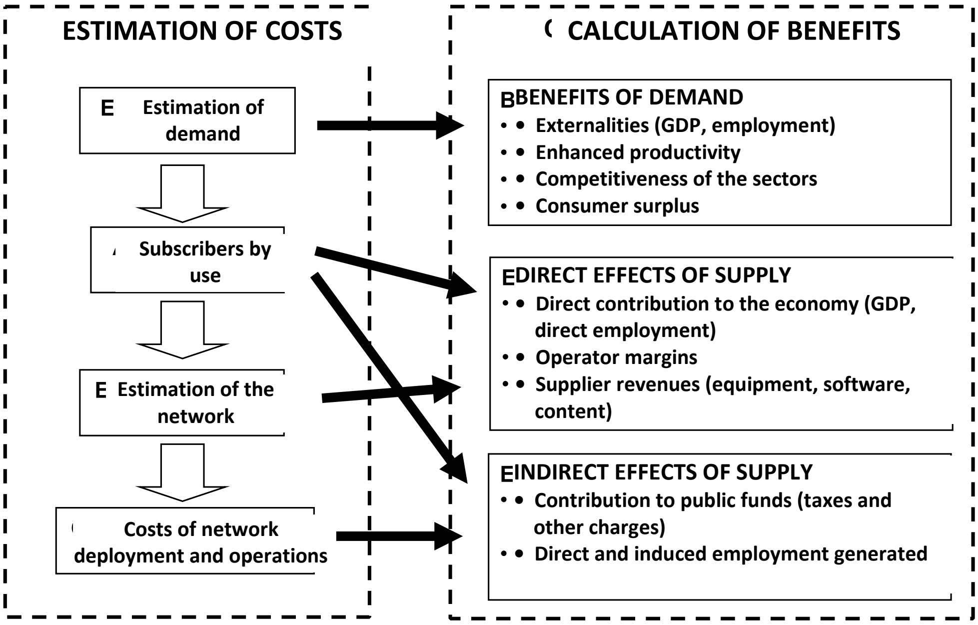
Source: Telecom Advisory Services

This demand model is based on three scenarios (Aggressive: fixed-mobile substitution; Basic: fixed broadband complementarity; and Conservative: usage stagnation, absence of crossed elasticities, infrastructure congestion).

In parallel with the forecasting of demand for mobile broadband, two scenarios need to be constructed with respect to the spectrum offering (with and without the possibility of using spectrum in the 700 MHz band). To this end, a number of assumptions need to be made as to spectrum assignments in the short term (in the 1.7, 1.9, 2.1 and 2.6 GHz, 800 and 900 MHz and also 1.8 MHz bands). For example, account has to be taken of the need for roaming required by the parallel operation of GSM networks. The deliverable in this case is the estimation of the costs of effecting the new deployment in the UHF band.

Once the analysis of demand and supply has been completed, the next step is to conduct a cost-benefit evaluation, assessing the desired impacts and costs of achieving them. The benefits are generally of three types: direct, indirect and externalities (see Figure 11).

Figure 11: Calculation of benefits

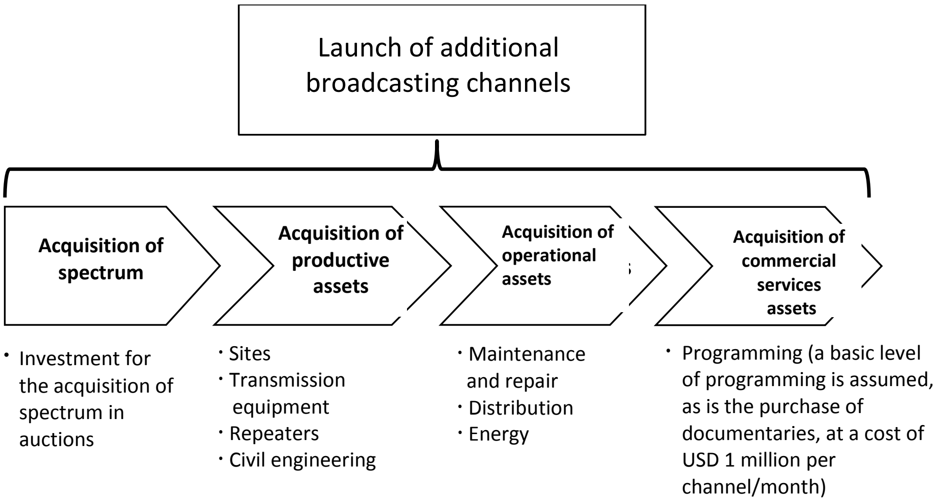


Source: Telecom Advisory Services

Direct benefit in terms of the creation of short-term direct employment is practically zero, since this assumes that the demand will be satisfied independently from the band usage. Externalities are observed both in the generation of employment within the economy and in productivity. In the interests of consistent comparison, the cost-benefit analysis should be affected in terms of net present value at a discount rate that is reasonable for the region.

Having concluded the cost-benefit analysis for mobile broadband, the next step is to estimate the future demand for broadcasting services (see Figure 12).

Figure 12: Economic contributions of the future offer of broadcasting services



Source: Telecom Advisory Services

In order to estimate the supply, it is necessary to understand the policy in respect of migration, the expected supply of high-definition (HD) and standard-definition (SD) channels, digital switch-off (the date thereof), open television vs. pay television, and multiplexing. The main assumption for the purposes of comparison is that practically all of the UHF spectrum will be used for some combination of digital terrestrial broadcasting services (DTT), although this may vary from country to country depending on the above-mentioned variables. It is important to point out that there is a basic scenario (the stated policy) that must be used when estimating the new deployment and transmission differentials and introduction of new channels (production and programming costs).

Based on the estimation of the broadcasting services supply, the comparative economic value is quantified both for mobile telecommunications and for broadcasting services. It is important to note that a very much broader supply of broadcasting channels, whether paying or free of charge, involves significant externalities that are difficult to estimate (for example, diversity, scope, access, equity, inclusion, democracy). Also to be noted is the "cannibalization" that exists between the main source of revenue (advertising) and the competition from other, alternative networks (cable, satellite). For the purpose of estimating the increase in value created, two main measurements are used:

- The additional amount consumers are prepared to pay for a broader satellite television offer to the home (in terms of subscription and equipment).
- How much more publicity resources will be captured by television sets (despite the current tendency to migrate to other media such as the Internet).

Once the process of quantifying the value of mobile telecommunications and broadcasting services has been completed, the two are compared. A cost-benefit analysis between use of the spectrum in the 700 MHz band for broadband services or for broadcasting services can then be made to assess the spectrum assignment ranking for each of them in order to maximize the value created for society. Where Digital Dividend 2 is concerned, the methodology is similar except that evaluation of the economic value for alternative scenarios has to be based on the services referred to in Table 7 (page 42).

5 Guidelines on assigning and using radio spectrum

This study's analyses of different trends regarding policy and economic impact of assigning and using radio spectrum enable us to formulate a number of guidelines that could be used by NRAs in the region. These are set out below and, where applicable, are linked to ITU Recommendations.

5.1 The importance of defining the national economic and social development goals that must be pursued in spectrum assignment and use

Any effort to plan future use and economic valuation of the radio spectrum must start by formulating the national economic and social development targets that are to be achieved by spectrum assignments. The spectrum is a public resource and its use is thus of fundamental importance in the rapid and effective development of mobile broadband, the consequent reduction of the digital divide by extending coverage of mobile services in rural and isolated areas, promotion of public services and, ultimately, the generation of revenues for governments through public auctions and the levying of taxes. In the case of Honduras, for example, frequency allocation policy is guided by the priority of furthering the universal deployment of mobile broadband, promoting competition, and, in second place, generating revenue for the State (Santos, 2015).

Defining the objectives entails formulating and prioritizing those national objectives. International experience of spectrum distribution shows that some of the objectives referred to above can come to be mutually contradictory. For example, maximization of revenue for the national treasury may be at variance with the promotion of service coverage, with a potential negative impact on the universal deployment of mobile broadband. For this reason, the first step in defining the principles of assigning and using spectrum should be to establish and prioritize the economic and social development objectives that will guide this process.

5.2 Requirement for long-term planning in assigning and using spectrum based on economic impact analysis

As noted previously in this study, demand for spectrum, as a basic resource for the mobile telecommunication industry, is evolving rapidly and requires frequent regulatory decisions, the absence of which could have adverse effects on quality of service and negative economic consequences for the development of a common-use technology and the best interests of consumers. NRAs must above all develop a long-term policy.[52] This should include:

- Analyses of the radio technologies best suited to meeting these objectives: evaluating technology standards in order to define the most appropriate frequency allocation and channel plans with due regard to the harmonizing recommendations of international bodies such as ITU Recommendations.
- The impact of these technologies on spectrum planning: assessing the potential impact of spectrum allocation on the development of new technologies and services.

Implications of these technologies for the national frequency allocation table and revisions of regulations and standards: once preliminary analysis is concluded in this area, compare the results with plans developed by other countries.

This strategy, to be developed by the administrative authority responsible for spectrum management,[53] must include as one of its inputs the views of other public bodies and organizations (for example ministries of education, health, security, and so on), as well as reflecting the points of view of public and private mobile operators. Given the margin for uncertainty in the longer term as regards evolution of spectrum supply and demand, it is advisable to use analytical techniques such as construction of scenarios and assessment of their relative probabilities[54] in the national strategy.

5.3 Using long-term planning as an analytical framework to facilitate tactical decisions as a means of adapting to changes in the environment

Given the highly dynamic nature of technological supply and demand for wireless traffic, the strategy to be applied should be sufficiently flexible to allow periodic adjustment (annual or biannual). These adjustments must be based on tactical decisions, which must be examined in an integral way, which means:

- Evaluating spectrum allocation in the context of any recent changes in supply and demand;
- Simulating possible modifications to the strategic decision; and
- Assessing the possible systemic effects of those changes on general spectrum allocation.

5.4 Long-term planning and tactical adjustments must determine how much spectrum to distribute and how many operators must participate in a national market

Apart from the technological criteria and those used to analyse capacity demand that guide spectrum distribution, governments in their national plans must consider which type of industrial organization and competitive model are to be established in the telecommunication/ICT industry at the national

52 See Recommendation ITU-R SM.1047 on National spectrum management, adopted in 1994; revised and updated in 2012 with Recommendation SM.1047-2 (09/2012).

53 See ITU-R report SM.2012-4 (06/2014), Economic aspects of spectrum management, p. 13, and ITU-R Report SM.2015, Methods for determining national long-term strategies for spectrum utilization, p. 3.

54 Op. cit., p. 6.

level. Analysis of the telecommunications market structure indicates that there are optimal points in competitive intensity that favour the interests of consumers (lower prices, greater innovation), while also ensuring the sector's long-term sustainability (allowing continued capital investment at an adequate level). Spectrum policies that stimulate unrestricted competition among multiple (five or more) operators can lead to friction effects (such as low profitability, which can lead to early exit from the market) that are not conducive to harmonious development of the sector. This appears to have been the experience of Argentina's recent 4G auction; despite the intention to promote competition beyond the three existing operators by setting aside a block for a new entrant, the fourth provider was unable to comply with the conditions and the block had to be reassigned to a state enterprise.

At the same time, spectrum distribution policies that lead to the creation of duopolies may be counterproductive from the consumers' point of view.[55] Spectrum distribution must be based on clear principles that relate to the intended competitive model. It is also appropriate to analyse international experience in terms of the quantity of spectrum that has been distributed, and the way in which it has been assigned in terms of the numbers of operators or service providers. One potentially useful source of information for determining this is the ITU ICTEye database containing the specific results of spectrum assignment derived from the ITU survey on regulation.[56]

5.5 Carefully defining a suitable auction model

From the regulator's point of view, designing the auction and selecting the most suitable model must take account of a number of factors:[57]

- Type of band(s) to be auctioned
- Type of valuation of the band (private or communal value)
- Behaviour of participants (neutrality or risk-aversion)
- Desired characteristics for the new market
- Type and amount of information to be made available on development of the auction
- Spectrum caps (multi-band, multi-auction)
- Medium- and long-term auction plans
- Coverage requirements
- Inherent fiscal charges
- Infrastructure sharing / secondary markets

NRAs must therefore avoid mechanical emulation of a given auction model. Selecting the most suitable model will need to be based on the specific conditions prevailing in the country, the market, and the spectrum being auctioned.[58] It is also important to bear in mind that governments must decide whether the auction model is the most appropriate for achieving the objectives that have been set. In general terms, auctions are considered to be an appropriate management mechanism where demand for spectrum exceeds supply.[59]

[55] See the case of Honduras, where two operators serve more than 99 per cent of users. Santos, D. (2015). Aspectos económicos de asignación uso del espectro. Comisión Nacional de Telecomunicaciones (Government of the Republic of Honduras, presentation to a workshop on "Directrices de política y aspectos económicos de asignación y uso del espectro radioeléctrico", Managua, Nicaragua, 4 September 2015).

[56] www.itu.int/net4/itu-d/icteye/FocusAreas.aspx?paramWorkArea=TREG.

[57] See ITU (2014). Resolution 9 (Rev. Dubai, 2014), participation of countries, particularly developing countries, in spectrum management, Geneva.

[58] In Nicaragua, the auction of frequencies in the 1.7-1.8 GHz band resulted in only one provider because the other bidders did not comply with the formal conditions that had been established. As a result, the auction yielded significantly less (USD 10 million) owing to lack of competition. (Telcor, 2015).

[59] See ITU (2014). Resolution 9 (Rev. Dubai, 2014), participation of countries, particularly developing countries, in spectrum management, Geneva.

5.6 Considering the development of secondary markets

The development of secondary markets[60] will allow the introduction of greater flexibility and efficiency in spectrum use. This must be done gradually in order to prevent distortions such as accumulation, hoarding and speculative behaviour.[61]

5.7 Consideration of alternative approaches to allow efficient spectrum use

Technological development (networks and terminal equipment) currently allows mechanisms for reuse of frequencies, which enhances the efficiency of spectrum use. The NRA should start looking into the possible application of technologies such as systems for using software-defined radio spectrum and cognitive radio systems to boost possible reuse of a scarce resource. The decision to use frequency allocation mechanisms, such as auctions, that do not strictly comply with the principles of economic efficiency may be supported by economic and social development objectives.

Similarly, as we see from the experience of countries such as the United States and United Kingdom, experience of using common-use spectrum for deploying Wi-Fi technologies can be especially useful for solving problems such as urban network congestion (by routing and coordination of networks[62]) and broadband provision in rural and isolated areas.[63]

These alternative allocation technologies and mechanisms must be accompanied by greater flexibility in the legal framework governing spectrum use, so as to adapt to constant technological innovation and market dynamics.

In summary, it is essential to bear in mind that in order to meet growing demand for traffic, there are basically four options:

- Improved technologies --> more Mbps/MHz;
- Better reuse (femto cells, etc.)--> more MHz/km^2;
- Network integration (e.g. Wi-Fi offload);
- More spectrum.

NRAs should therefore consider and evaluate these aspects in order to determine the actual demand for spectrum and define spectrum efficiency indicators.

5.8 Developing internal capacity of the spectrum management authority to estimate the economic value of spectrum

An estimate of the economic value of the spectrum to be assigned will enable us to determine the expected auction revenues. This valuation will allow a reserve price to be determined for each block. It will also allow us to define the recurring charges levied on operators so as not to compromise their financial sustainability. For this, as has been noted in previous sections, it is essential to:

- Use an analysis of comparable prices;
- Calculate the opportunity cost associated with participation in an auction;
- Use the resulting spectrum cost as an input in overall valuation of deploying a given network;

60 See ITU-R (2012), Economic aspects of spectrum management, Geneva.

61 See report ITU (2014). Resolution 9 (Rev. Dubai, 2014), participation of countries, particularly developing countries, in spectrum management, Geneva.

62 See Katz, R. (2014). Assessment of the economic value of unlicensed spectrum. New York: Telecom Advisory Services LLC.

63 See Katz, R. and Beltrán, F. (2015) "Socio-economic impact of alternative spectrum approaches in Latin America". *Proceedings of the 9th CPR LATAM Conference*, Cancun, 14-15 July.

- Consider macroeconomic factors (for example, limited availability of capital) or competitive factors (for example, over-supply of spectrum, or auctions in neighbouring countries) that could adversely affect the valuation.[64]

5.9 Consideration of the fact that, if auctions are used for frequency assignment, lack of transparency may affect the estimated economic value

Lack of transparency, or opacity, in the rules governing the conduct of an auction raise the level of uncertainty for the participants.[65] A high level of uncertainty could imply raising the risk factor in any valuation of the spectrum under auction, resulting in a drop in its value. Clarity in the rules and transparency in processes do not have only legal value; they help to reduce the risk factor in the valuation of spectrum supply and thus enhance value. Transparency results from the publication of clear rules covering all spectrum access alternatives, and an analysis of the market environment and the competition model to be adopted. Transparency in the process includes not only the auction rules but also all aspects relating to payments, penalties, construction permits, and so on.

5.10 Continually implementing economic analysis to maximize the economic and social benefits of appropriate spectrum management

Apart from the criteria of technical and micro-economic efficiency on which spectrum allocation decisions should be based, it should be recalled that in the final analysis spectrum is a basic public resource for the economic and social welfare of the population. Management decisions must constantly take into account, through rigorous economic analysis (in this case based on estimates of consumer surplus), the impact on users, in terms of quality of service, coverage and innovation. These criteria should inform not only the long-term plan described above but also any decisions regarding the award of licences.

5.11 Implementing changes regarding organization and human resources in order to build analytical capacity within the spectrum management body

As every spectrum-related decision entails a series of economic analyses (valuation of bands, impact analysis with regard to allocation decisions, and so on), it is essential for the spectrum management authority to attract and train staff to carry out these analyses, while also being able to accept in a critical way any input from mobile communications users, operators and equipment manufacturers.

6 Conclusions

The aim of this study has been to formalize some guidelines on policy and economic aspects of radio frequency assignment and use, and thus to help both NRAs and operators to optimize their use of this scarce resource. As is made clear in the available literature on this topic, economic valuation of spectrum is one of the main means of introducing efficiency into spectrum management. For this reason we began by defining the economic principles that govern the spectrum assignment and use in a way that also takes account of its social value.

The basic principle is founded on the fact that spectrum is a scarce public resource and a diverse one, which cannot be stored but can be negotiated. These characteristics mean that access to and use of

[64] This may be the case with the experience of Bolivia, where the price per MHz in the auction of the 1.7/2.1 GHz and 700 MHz bands was USD 765 383, while the estimate based on comparable prices based on GDP reached USD 1 373 218 (ATT, 2015).

[65] See ITU (2014). Resolution 9 (Rev. Dubai, 2014), participation of countries, particularly developing countries, in spectrum management, Geneva, p. 25.

spectrum must be administered by the public authority. Administration includes planning spectrum use, granting authorizations and licences, and monitoring and controlling spectrum use. Spectrum administration must aim as far as possible to achieve three objectives: economic efficiency, technical efficiency, and social benefit. Economic efficiency seeks to maximize the added value of using services produced by available spectrum. Technical efficiency guarantees maximum use of spectrum and quality of service. Social benefit is based on the establishment of a competitive model that guarantees benefits for consumers.

Having established the economic, technical and social principles of spectrum management, the study considered different spectrum assignment models and described the various auction models. It was established that selection of a suitable model must be based on such factors as promotion of efficient spectrum assignment, stimulating competition in the industry, stimulating participation in auctions, generating revenues for the government, and improving geographical coverage of networks. The principle to keep in mind here is that there is no one "best" model.

In addition to the traditional models of administrative assignment and assignment by auction, in-depth consideration was given to two relatively new mechanisms: the secondary licence market, and the various sharing models. It was concluded that while a number of countries in Latin America have introduced licence transfers or leasing for spectrum use in the secondary market, this has not so far resulted in significant transactions. As regards sharing mechanisms, various mechanisms were studied based on sharing of frequency bands or infrastructure, geographical spectrum use and geolocalization databases for using "white spaces", techniques based on cognitive and software-defined radio, among others. More recent thinking suggests that this is an area that warrants evaluation by NRAs.

Having considered different assignment models, the study then looked in detail at the various methodologies used to valuate spectrum. The most widely used is the use of comparable results (*benchmarking*), based on the results of previous auctions or secondary transactions conducted in the same country or other countries. This was followed by a review of the avoided costs models, which estimate the investment that would be required from operators in order to respond to the growth in traffic if they did not have access to the spectrum in question. In the business case estimation model, the financial benefit (in terms of discounted cash flows) derived from access to the spectrum bands is calculated. The opportunity cost method is based on a calculation of the value generated by use of the spectrum in various alternative mobile telecommunication applications.

In particular the methodology of valuating unlicensed spectrum (known as common-use bands) was examined, with a detailed look at four complementary methodologies: the complementary value in relation to exclusive-use licences; the value of alternative technologies using the licence; the value of alternative business models; and the value of expanding public networks based on the complementarity of common-use bands. In methodological terms, these principles can also be applied in valuating the economic and social benefit of bands subject to digital dividends 1 or 2.

An examination of these topics enabled us to draw up guidelines that can be used by NRAs to create technical capacity for the economic valuation of spectrum, in particular in order to:

- Define the national economic and social development objectives that are to be pursued when allocating and using spectrum
- Implement long-term planning in spectrum assignment and use based on economic impact analysis
- Use long-term planning as an analytical framework allowing tactical decisions in response to changes in the environment
- Long-term planning and tactical adjustments must determine how much spectrum is to be distributed, and how many operators must participate in a given national market
- Carefully define the appropriate auction model
- Consider development of secondary markets

- Consider alternative approaches to facilitate efficient spectrum use
- Develop internal capacity within the spectrum management authority to calculate the economic value of spectrum; it is important to implement the changes required in terms of organization and human resources in order to build internal analytical capacity of the spectrum management authority
- Consider that, in cases of spectrum assignment through auctions, lack of transparency may affect the estimated economic value of the spectrum
- Implement continual economic analysis with a view to maximizing the economic and social benefits ensuing from appropriate spectrum management.

While there is no "single theory" that tells us show to valuate and manage spectrum efficiently, the regulatory practice and experience of other countries have helped us to define a set of tools, principles and guidelines that will help governments to administer spectrum use in ways that benefit their populations.

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