ACCELERATING THE INTRODUCTION OF SPECTRUM SHARING USING MARKET-BASED MECHANISMS

Fernando Beltrán
University of Auckland Business School
June 2016

ABSTRACT

Spectrum management needs to be effective, in that spectrum must be allocated to the right uses, and efficient, in that spectrum must be assigned to those that value it the most. Technological advances and demands for further spectrum availability from mobile broadband operators (among others) require spectrum management to timely and firmly incorporate schemes to increase the technical efficiency of spectrum utilisation. One such scheme is spectrum sharing which has the potential to result in higher spectrum utilisation and greater spectrum value. In such context allocation and assignment, two critical functions to manage the spectrum, are also discussed. It is argued that in the course of deciding about allocation and assignment of spectrum, a spectrum authority can and should include market-based mechanisms that incentivise incumbents to share spectrum needed by entrants.

***Keywords*—** Spectrum management, spectrum sharing, ICT, General Purpose Technologies, licensed shared access, unlicensed spectrum.

1. INTRODUCTION

Radio spectrum has played, is playing and will play a fundamental role in the development of communications networks and services. The unparalleled rise of the cell phone and the quiet revolution in data communications brought about by Wi-Fi and other wireless data technologies demonstrate that effective management of the spectrum is the foundation to robust wireless markets and innovative wireless services.

This paper examines spectrum management as the vehicle deployed by governments to achieve key objectives such as maximising the value of spectrum, its efficient utilisation and its benefits to society. If spectrum management creates conditions for achieving such objectives, it will grant spectrum the affordances that make Information and Communications Technologies (ICT) the kind of disruptor that exhibits considerable technological progress, pervasive use in a wide range of economic sectors, a booster for complementary innovations and a generator of important spillover effects.

Essentially spectrum management is the government function that organises and regulates the utilisation, allocation and assignment of blocks of frequencies so that interference between uses in contiguous bands is minimised. In order to address scarcity and underutilisation of spectrum, spectrum sharing is rising to the top of the agenda of spectrum authorities in many countries. Such institutions have initiated reviews of their national guidelines for spectrum management in order to incorporate spectrum sharing to their regular processes of spectrum allocation and assignment. A review of spectrum sharing policies is included in a later section.

Spectrum management has evolved from its early days when it was focused on interference avoidance [8] to a more modern view whereby, additionally, the spectrum authority seeks to maximise its value [7]. Spectrum value is defined by establishing who derives value from its usage and what the right measurement of value must be. A broad conception of value as found in Barwise et al [2] considers three components of value: private use value, private external use value and social value.

A SA's arsenal of policy tools and regulations can be enhanced with the inclusion of spectrum sharing as a management scheme aimed to increase the effectiveness of allocations and the effectiveness of assignments. The decision-making process that leads to the assignment of frequency bands to competing parties is based on administering an auction that sells a number of blocks in a number of geographical areas. Although traditionally auctions have assigned spectrum licenses on an exclusive basis, using them to assign shared rights is not only conceivable but possibly an efficient pathway to introduce market mechanisms to decide who gets to share the spectrum.

This paper will first introduce, in Section 2, the concept of General Purpose Technologies -which helps explain the importance of certain technologies to the economy at large- to support its argument that Information and Communications Technologies are of such kind. Spectrum management is discussed in Section 3, while particular aspects and variants of spectrum sharing are presented in Section 4. In Section 5 the paper argues that market-based mechanisms can be used when a spectrum authority decides to broaden the role of spectrum sharing in future processes of spectrum allocation and assignment. Section 6 concludes

2. ICT AS A GPT

One theoretical element that helps comprehend ICT's impact on economic growth is the concept of General Purpose Technologies (GPT). GPT can be defined as "a

single generic technology, recognizable as such over its whole lifetime, that initially has much scope for improvement and eventually comes to be widely used, to have many uses, and to have many spillover effects" [11]. A GPT is usually a crude technology that evolves to encompass a broad range of uses, usually applied in the production of a wide range of outputs [11]. In a sense a GPT is an opportunity enabler that opens the door to other technologies and uses, its efficiency improving as it diffuses through an economy. GPTs may transform the economic, social and political structures that embrace them; such GPTs are known as "transforming GPTs". As an illustration, though not widely accepted, Lipsey et al. [11] list 24 transforming GPTs throughout modern human history including domestication of animals, wheel, iron, printing, internal combustion engine, electricity, mass production, computer, Internet and biotechnology.

Although there are sceptics, ICT is generally recognized as a GPT. This means that it is seen as sharing GPTs' unique characteristics, characteristics that differentiate them from conventional economic goods and services. GPTs are innovations that are slow to develop and diffuse yet gradually impact most activities in the economy. GPTs are defined within historical time, i.e., they start at a point in time, they expand to eventually mature and give way to other technological changes [11]. Its historical dimension that makes GPTs contribute to business cycles. For instance, in its first phase, ICT diverts resources from other economic activities with a corresponding slowdown of the economy. Some argue that this is partially what happened with ICT and the productivity slowdown from the early seventies to the nineties [1].

Characterising ICT as a GPT, Rincon et al [17] state that ICT exhibits considerable technological progress and its use is pervasive in a wide range of economic sectors; it is also considered a booster for complementary innovations and a generator of important spillover effects. In the wireless communication sector those characteristics are propelled by access and utilisation of the radio spectrum. The spectrum's transformation from a carrier of analog signals to a carrier of digital information has allowed many sectors to take advantage of its pervasive use. The utilisation of spectrum frequencies continues to fuel a high rate of technological progress both for manufacturers of wireless devices and equipment as well as for developers of software solutions for wireless applications. In their study Rincon et al [17] found that spillover effects, although negative in the short-term, turn to positive after about five years of initial investments. They also find that spillovers across industries are positive and significant.

Seen through the lens of the GPT concept, the effects of ICT have not only been beneficial to the technology and telecommunications sectors per se but to the wider economy across and society. Deployment and innovation in ICT has become intimately linked to the smart utilisation of the radio spectrum. Ever since ALOHA started to transmit packets of data back in the late 1960s the smart manipulation of data signals that use the spectrum to propagate and carry information has been a continuous source of innovation in wireless communications. However, since spectrum is a public resource traditionally overseen by government, spectrum management has been rather slow and struggles to keep up with innovations.

3. SPECTRUM MANAGEMENT

Since the times when radio spectrum was first used to guide ships on their Northern Atlantic routes and later commercially by early radio stations, the need for organising it in channels without signal interference was quickly acknowledged [8]. Minimising interference and assigning bands to a handful of uses were therefore the focus of early spectrum management. Fast forward to the second decade of the 21st century and the scope, complexity and diversity of tasks associated with spectrum management are daunting. Its modern conception as stated by Cave et al is '*to maximise the value that society gains from the radio spectrum by allowing as many efficient users as possible while ensuring that the interference between different users remains manageable*' [7]. In other words in addition to interference manageability, Spectrum Authorities (SA) seek to allow more users to use spectrum and more value to be derived from it [3], [4].

Currently the most noticeable trend in spectrum management is a shift away from command-and-control to a market-based approach where users and applicants to licenses act within an incentive-based institutional framework expected to lead to efficient spectrum use. When foreseeing the potential~~ly~~ commercial use of a band, typically SAs have relied, first, on deciding the type of use the band will be given to, and then, providing a license to one or more operators for its exploitation. The former is known as **spectrum allocation** and the latter is known as **spectrum assignment** [7].

Every SA seeks to keep excessive interference from occurring and in so doing they keep tight control on allocating spectrum to uses in such a way that similar services tend to cluster in similar bands. The SA is also charged with assigning the spectrum to diverse users. When spectrum supply exceeded demand, assignment would occur in a very straightforward basis; as time went by and technological advances started to demand more and more spectrum, lotteries and other administrative processes were used to assign the spectrum. Soon the flaws of lotteries were revealed and a long held theoretical proposal became reality: auctions became the mechanism of choice to assign radio frequencies to users. Still, assignment entailed licensing, so licences would protect the holder from undue interference from other spectrum users. Licences were issued on relatively long periods of time, which meant risks associated with technology and policy changes were eliminate in favour of the licensee.

A range of services and applications have benefited from decisions to exempt users of certain bands from licensing. Cordless phones, remote controls and wireless Local Area Networks operate on that basis. The decision to allow for such commons, especially for Wi-Fi technology, has opened tremendous opportunities for innovation in wireless

communications. It reveals the importance of having tried a non-conventional way at the time of spectrum utilisation.
SAs face quite a number of challenges. Spectrum management needs to embrace new approaches and, in some cases, a full overturn of traditionally held views. It is the case of spectrum value maximisation.
In the UK, the Department for Culture, Media and Sport, DCMS, [2] identifies three components of value: private user value, private external value and social value. Private user value, also known as the economic value of spectrum is defined as the present value of the discounted future profits earned by way of using the spectrum [3], [4]. Value is affected by revenues, costs and uncertainty. Private external user value refers to the externalities that arise from the use of spectrum by other users. Social value of spectrum gathers all expressions of value that are not directly attributable to economic activities that may profit from spectrum. Most social value resides in the spectrum allocated to defense, security and public affairs.

4. SPECTRUM SHARING

The preceding discussion pointed at the need for more spectrum management flexibility since the "command and control" or long-term exclusive use approach has proven to be quite a static and rigid management approach. It has been argued that such models have contributed to spectrum scarcity [16]. From a technical perspective, a more dynamic spectrum management is possible if and when new techniques that enable the redefinition of radio frequency parameters, such as the frequency, modulation or output power are allowed to operate.
The combination of new technology, improved radio transmission techniques, and flexible and innovative rules on the use of spectrum facilitate an increasingly attractive aspect of spectrum management which is gathering renewed interest and, in a way, being demanded by enthusiasts and experts: the shared use of the spectrum. Spectrum sharing started with decisions that split the use of bands with strong provisions against interference and has evolved into decisions that have designated some spectrum bands as unlicensed, and therefore free to be used by any device within technical parameters dictated by standards, and more recently into regulatory frameworks promulgated by some SAs. If policy makers and SAs are receptive to spectrum sharing, it may develop as a key spectrum management tool to use, allocate and assign spectrum to achieve the main management objectives discussed above of value maximisation and interference minimisation.
Spectrum sharing is a spectrum utilisation scheme that allows two or more parties to utilize the same range of frequencies while no exclusivity is granted to any of them. Milgrom et al. [13] argue that a combination of licensed and unlicensed approaches to spectrum assignment may unfold in innovative services which would in turn lead to increased social benefits. Licenses provide rights and obligations whereas unlicensed used of the spectrum, like a no-frills use, is subject to the hassles and inconveniences of the commons.
Spectrum sharing is not concerned with licensing per se; rather it is a spectrum utilisation scheme that erodes exclusivity in spectrum access and utilisation. In recent years several technologies such as Software Defined Radio and Cognitive Radio (CR) have been developed to make shared use of the spectrum possible. Such radios are capable of providing dynamic access to the spectrum, whereby radio frequency parameters are adjusted dynamically to optimize spectrum usage. A conspicuous example is IEEE 802.22 also known as Wireless Regional Area Network or WRAN, a technical standard that includes CR techniques able to use spectrum allocated to television broadcasters under direct coordination of a central database, which keeps up-to-date information about current band utilisation. WRAN is meant to be deployed in rural, low-density geographical areas where broadband access is non-existent. The standard is first of its kind as it is meant for the opportunistic use of frequencies associated with TV bands – known as white spaces- while allowing no interference.
Either through new technologies or through purely administrative allowances that make it possible for several users to share a band – shifting the burden of agreeing to interference-free operation onto those users, spectrum sharing arrangements challenge the conventional management approach to commercial use, especially for mobile telecommunications services, that has for long conceived spectrum as a resource that must be granted on an exclusive basis [16].
Spectrum sharing can be implemented in one of a range of variants. For instance, license-exempt bands allow the use of a band by any device that complies with a pre-specified technical standard; IEEE 802.11 or Wi-Fi is the best example of it; or bands shared by licensed and license-exempt applications and, licensed and light-licensed commons [18].
In the UK Ofcom has recently released its Spectrum Sharing Framework [14], which provides mobile and wireless broadband operators with legal room to initiate a request to gain access to share specific bands. After consultation with the market, Ofcom summarised the framework in three main aspects that: 1. state the characteristics of use for prospective users who seek access to shared spectrum; 2. advise on the nature and strength of barriers that may limit the future of spectrum sharing; and, 3. discuss the market and technology regulatory tools and enablers of spectrum sharing. Acknowledging that sharing may be detrimental to a licensee's interests, Ofcom will need to decide when spectrum sharing is economically and technically feasible and how it represents a beneficial alternative to the status quo; otherwise it must maintain the current allocation untouched.
In 2009 New Zealand introduced the Managed Spectrum Park (MSP), a special type of licensed commons that operates in the 2575-2620 MHz band. With such scheme the government has sought to encourage "a flexible, cooperative, low cost and self-managed approach to allocation and use" [12] of the spectrum. A MSP allows access to a number of users – usually operators of

communication services such as wireless broadband- to the common band on a shared basis and is intended for local and regional services; applicants to a MSP only seek to cover small geographical areas and do not need or want a nationwide license. Sharing may take several forms: it may be that two or three operators split the available bandwidth in an arrangement whose technical aspects need to be sorted out by private agreements, or it may consist of a geographical split within the licence's region.

The European Commission has established two models for sharing frequencies [9]: CUS or Collective Use of Spectrum, and, LSA or Licensed Shared Access. CUS is a license-exempt mode that allows more than one user to use a spectrum simultaneously and with no requirement for a license; variants of the commons fit within the CUS approach. On the other hand, LSA is a scheme which combines traditional command-and-control management with an explicit allowance to share spectrum; in a LSA a limited number of parties are licensed to totally or partially use the band under sharing rules, which have been approved by the SA and then included as terms in the license [18].

Authorised Shared Access (ASA), a special type of LSA promoted in the European Union, is as a mechanism by which a new licensee is granted temporary access to the spectrum already assigned to an incumbent under the prescription that the incumbent does not use it [18]. ASA will allow an access seekers to deploy cognitive radio techniques that will help it learn about on-the-spot channel availability. Such scheme requires bilateral negotiations between the new licensee and the incumbent. ASA also allows multiple new licensees access to one or more incumbents' licensed spectrum.

The illustrations provided above indicate that SAs are attracting attention in different regions. Incorporating of spectrum sharing is a process that threatens the conventionally accepted exclusivity of spectrum rights and acknowledges that technology progress and political willingness can come together to favour the introduction of Dynamic Spectrum Management. Such transition surely is a slow process and will require the introduction of legislative and regulatory changes.

5. EFFECTIVENESS OF SPECTRUM ALLOCATION AND EFFICIENCY OF SPECTRUM ASSIGNMENT

This section discusses effectiveness and efficiency in the context of spectrum allocation and spectrum assignment, respectively. It then turns to argue that spectrum sharing provides a renewed management tool to increase the effectiveness of allocations and the effectiveness of assignments, which should translate into additional benefits to society at large.

The typical problem a SA faces is the following: what is the best use that can be given to a given frequency band and who should be entitled – or licensed – to use it?

As discussed above a SA allocates a spectrum band to a service or services that can occupy the band. International agreements and harmonisation in the possible uses of the spectrum have led SAs to designate radio spectrum bands for their utilisation by prescribed services, which in many cases must follow technical standards of transmission and interference management. Assignment of spectrum to users follows an administrative process that grants them rights over a number of bands Most SAs use auctions for assigning spectrum in bands allocated to commercial communications and broadcasting operations.

Building upon Larbi-Apau and Moseley [10] who state that effectiveness means doing the right thing while efficiency is about doing the things right, it is here suggested that if a SA puts spectrum to its best use, it will maximize the effectiveness of the allocation, and if a SA puts the spectrum in the hands of those who value it the most, it will maximize the efficiency of the assignment. It is clear, from the evolution of some of the so-called ISM bands –such as 2.4 GHz and 5.8 GHz, which were originally conceived for applications non-related to telecommunications, to become the support of Wi-Fi systems, that allowing non-licensed, open access use of the spectrum can create conditions that demonstrated the effectiveness of spectrum management.

In considering spectrum sharing a SA would need to ask itself how the introduction of sharing will affect its main spectrum management functions. In particular it is adequate to wonder what the impact of spectrum sharing would be on allocation and assignment.

In some cases SAs are pressed from different directions to allow new users, particularly wireless broadband operators and other providers of newly developed services to access spectrum bands which are being cleared up from their previous licensees. The US 700 MHz band is one case at hand in which several competing parties demanded that the Federal Communications Commission should designate the digital dividend – those bands left empty by the introduction of digital television – to their particular uses of interest. On one side, mobile telecommunications operators demanded those bands be allocated to 4G services and an auction administered to assign extensive geographical licenses. On the other side, new comers – among them information and contents operators as well as some equipment manufactures - demanded those bands should be designated unlicensed and opened for common exploitation by Wi-Fi services. One interesting proposal was to design an auction that would solve both problems jointly: allocation and assignment. The auction design, proposed in Bykowsky et al, [6] would allow both types of potential buyers to bid in an auction whose outcomes would determine who would use the spectrum, and in doing so also deciding the service, as well as the amounts to be paid for the licenses. By introducing a slight change to such auction design, which would restrict the use of those bands to the fringe of participants interested in the unlicensed option, a SA would be shifting the burden of spectrum allocation decision to a market-based mechanism that simultaneously over the course of a clock ascending auction would decide whether a band is to be shared or not, and it is, the price to be paid for a shared license. Potential sharers need to solve a collective action problem; in such

situations, typically efficiency of the allocation may be compromised as bidders find incentives to free-ride.

Opportunistic use of a frequency band, as enabled by WRAN technology, requires a centralized database to allow CR-based devices to transmit on TV white spaces. Establishing and managing – or outsourcing - such a system requires that the SA covers the costs of equipment and administration. ASAs such as this would probably have to be funded, at least partially, through license fees but most likely will need to be subsidized as the target population is usually sparse and remotely located from urban centres.

A common inquiry raised by potentially new users to SAs is about the efficiency with which government agencies that use parts of the radio spectrum use it, indicating too that they would need shared access to such bands. In the UK Ofcom, upon releasing its spectrum sharing framework, outline the request process as one by which a mobile operator or interested party initiate a request to gain access to a specific band that has been either licensed to an incumbent or held by users, such as government agencies, traditional holders of rights. The spectrum access seeker needs to have exhausted a number of options that must precede their sharing aspirations; first, it must have not found any suitable option among the currently available licenses (including license-exempt bands), or found no trading or leasing opportunities. Only then Ofcom will consider looking into available information to determine whether the request is worth being further investigated.

Building provisions to endow spectrum sharing decisions with market-based mechanisms was attempted by Ofcom with its 800 MHz and 2.6 MHz spectrum auction in 2013. In 2012 Ofcom's consultation on the award of those bands, ample consideration was given to auction rules that would lead bidders to reveal preferences for wining bands contiguous to bands won by other bidders with whom potential sharing agreements could be reached [15]. The proposal first explored the pros and cons of allowing bidders to express their preferences consistent with their goal to get blocks contiguous to the blocks won by other bidders with whom they would be sharing the spectrum. Bidders would see benefits from pooling together resources with higher speed and improved quality of service possibly achieved. Bidders, on the other hand, would be exposed to the risk involved in not being able to win the necessary blocks, hence the likelihood of an inefficient auction outcome. This is another instance of collective action that requires coordination between bidders over the course of the action, a situation hard to deal in the context of auction rules that protect anonymity of bidding. Eventually for its 2013 auction Ofcom decided not to facilitate joint bidding or spectrum sharing.

6. CONCLUSIONS

The modern role of spectrum managers has become even more challenging as demand for spectrum has increased remarkably over recent years. Bandwidth-hungry applications and devices seek to get connected over the airwaves is dismal numbers but the availability of spectrum is not keeping up with demand. This paper argues a renewed role for spectrum sharing needs to be embraced by spectrum authorities as other managerial decisions such as reallocation, clearing of non-highly used bands and refarming are not enough. In doing so spectrum management is continuously expected to be serve as the vehicle deployed to maximise the value of spectrum, its efficient utilisation and its benefits to society.

Spectrum sharing can enhance the spectrum authority's capabilities with a management scheme aimed to increase the effectiveness of allocations and the effectiveness of assignments. Market-based mechanisms that include auction for the assignment of rights to share the spectrum are not only conceivable but possibly efficient ways to decide about the best use and user of the spectrum [5].

If spectrum management creates conditions for efficient allocation and assignment through spectrum sharing, it will be fueling the connection between policy and markets that make Information and Communications Technologies (ICT) a pervasive factor in a wide range of economic sectors, a booster for complementary innovations and a generator of important spillover effects.

REFERENCES

[1] Aghion P, Howitt P, Violante G. (2012). General Purpose Technologies and Within-group Inequality. Journal of Economic Growth.

[2] Barwise, P., Cave, M., Culham, P., Lavender, T., Pratt, N., and Tambini, D. (2015). "Incorporating Social Value into Spectrum Allocation Decisions". A report for UK Department for Culture, Media and Sport.

[3] Bazelon, C. and McHenry, G. (2014). "Spectrum Sharing: Taxonomy and Economics". The Brattle Group.

[4] Bazelon, C. and McHenry, G. (2013). "Spectrum Value". Telecommunications Policy. 37, 737-747

[5] Beltran, F., Ray, S.K., and Gutierrez, J. (2016). "Understanding the current operation and future roles of wireless networks: Co-existence, competition and co-operation in the unlicensed spectrum bands". UoA-AUT-MIT Working paper.

[6] Bykowsky, M.M., Sharkey, W.W., and Olson, M. (2008). "A Market-Based Approach to Establishing Licensing Rules: Licensed versus Unlicensed Use of Spectrum" US Federal Communications Commission, OSP Paper 43. https://www.fcc.gov/reports-research/working-papers/market-based-approach-establishing-licensing-rules-licensed-versus

[7] Cave, M., Doyle, C, and Webb, W. (2007). Essentials of Modern Spectrum Management. Cambridge University Press.

[8] Coase, R.H. (1959). The Federal Communications Journal of Law and Economics, Vol. 2., 1-40.

[9] European Commission (2016). "Promoting the shared use of Europe's radio spectrum". https://ec.europa.eu/digital-single-market/en/promoting-shared-use-europes-radio-spectrum (last access, April 28, 2016).

[10] Larbi-Apau, J. A. and Moseley, J. L. (2010), Performance-based measurement: Action for organizations and HPT accountability. Perf. Improv., 49: 7–17.

[11] Lipsey, R., Carlaw, K.I., Bekhar C.T. (2005). Economic Transformations: General Purpose Technologies and Long Term Economic Growth. Oxford University Press.

[12] MBIE Ministry of Business, Innovation and Employment (2010). Managed Spectrum Parks Allocation Rules. New Zealand Government. www.rsm.govt.nz
[13] Milgrom, P., Levin, J., and Eilat, A. (2011). "The case for unlicensed spectrum". Stanford Institute for Economic Policy Research Discussion Paper No. 10-036.
[14] Ofcom (2016). "A framework for spectrum sharing". Available at http://stakeholders.ofcom.org.uk/binaries/consultations/spectrum-sharing-framework/statement/statement.pdf Last access April 24, 2016.
[15] Ofcom (2012). "Second Consultation on assessment of future mobile competition and proposals for the award of 800 MHz and 2.6 GHz spectrum and related issues". http://stakeholders.ofcom.org.uk/binaries/consultations/award-800mhz/summary/combined-award-2.pdf Last access May 30, 2016.
[16] PCAST (2012). Report to the President: Realizing the Full Potential of Government-held spectrum to spur economic growth.
[17] Rincon, A., Vecchi, M., and Venturini, F. (2013). "ICT as a General Purpose Technology: Spillovers, Absorptive Capacity and Productivity Performance. UK NIESR Discussion Paper 416.
[18] SCF Associates (2012). "Perspectives on the value of shared access". Final report for the European Commission.