XVIII CONFERENZA

SERVIZI PUBBLICI.
Nuove tendenze nella regolamentazione, nella produzione e nel finanziamento

Pavia, Università, 14 - 15 settembre 2006

# SPECTRUM MANAGEMENT AND REGULATION: TOWARDS A FULL-FLEDGED MARKET FOR SPECTRUM BANDS?

LEO FULVIO MINERVINI and DIEGO PIACENTINO

pubblicazione internet realizzata con contributo della

# SPECTRUM MANAGEMENT AND REGULATION: TOWARDS A FULL-FLEDGED MARKET FOR SPECTRUM BANDS?

Leo Fulvio Minervini* and Diego Piacentino**

## 1.- Introduction

The increase in spectrum demand which has occurred, internationally, in the last 10-15 years (as a consequence of booming wireless communications) has placed considerable pressure on traditional (administrative, command and control) regulatory arrangements for spectrum access and use. As two commentators have stated recently, "[t]oday, the radio frequency spectrum is the shared resource that perhaps most strikingly and most pervasively affects the well being of society" (Baumol and Robyn 2006: 1-2); but command-and-control arrangements are poorly suited to ensure efficient spectrum management.

While market developments produce a shifting structure of applications and spectrum demands (Benkler 2002, Cave 2002, EC 2005a, Analysys and Mason 2005, Ofcom 2005a), the adjustment of command-and-control regulation is hindered by uncertainty as to current and foreseeable developments—not to mention opposition from incumbent spectrum users, who are obviously reluctant to release spectrum bands for use by new entrants.

Governments, especially in industrial countries, have taken a number of steps of remedial policy *vis-à-vis* these difficulties. On the one hand, they have increased the share of spectrum made available for commercial use, by releasing spectrum bands previously held for use by the public sector (typically, the military); on the other hand, they have injected flexibility into command-and-control regulation, by auctioning spectrum bands, allowing (to some extent) secondary trading, permitting new, innovative ways of commercial access to spectrum use (airtime resale, virtual network operation), widening unrestricted access to spectrum bands (ITU 2004).

* University of Macerata and University of Warwick.
** University of Macerata.

These are, however, steps of a temporary, palliative nature. The reserve of spectrum bands in the hands of the public sector is limited, and shrinking as long as re-allocation measures are effected; at the same time, flexibility measures, by addressing specific issues and spectrum bands, fall short of giving an organic solution to the problem of spectrum management. A smooth migration of applications across radio frequencies and implementation of new transmission technologies is not ensured; as a consequence, inefficient spectrum use is a permanent feature of the development of communication systems.

These considerations lead to the theme—and questions—of the present paper. While it is clear that efficient spectrum management should allow for full competition among users and applications (i.e. for full flexibility in spectrum use), it remains far from clear what arrangements could best sustain such competition and flexibility.

There is an apparent similarity in structure between this allocation problem and others which economic reflection is familiar with, regarding a considerable variety of fields—from pollution rights to airport slots. Allocation of spectrum bands, however, shows a distinctive feature: the solution along Coasian lines, involving property rights and market exchanges (Coase 1959, 1960), which is customarily proposed for this kind of problems, finds considerable support [e.g., Hazlett (1998, 2003), Kwerel and Williams (2002), Baumol and Robyn (2006)]; but, especially in the American literature, this proposal meets a competing one, involving the management of spectrum as a commons, and very limited regulation aimed to interference control [e.g., Noam (1998), Benkler (2002), Werbach (2004)].

Starting from a discussion of the limitations of command-and-control regulation, this paper considers the two main, alternative approaches which have been proposed—namely, a (Coasian) market regime, and a commons regime, respectively; then, after taking side in favour of the market regime, consideration is given to some implementation issues, and to a regulatory formula—called administrative incentive pricing—which can help ensure a smooth transition from command-and-control to market arrangements.

## 2.- Interference management under the command-and-control approach

Under the command-and-control approach, harmful interference is prevented by means of regulations allocating (technologically usable and commercially valuable) spectrum bands to users and applications. Allocations involve, typically, licensing and exclusive rights; in a few cases, however (like CB communications), allocations allow free access and joint use; as a rule, bands are generously sized, and distanced from each other by means of cushion—guard—bands; finally, no (substantial) payment is required for access and use.

Adoption of this approach has large, and well known, efficiency costs (Hazlett and Muńoz 2004, Ellig 2005). It is an inherently conservative approach, with respect to a situation which is rapidly shifting, in response to technological and economic change: on the one hand, as market signals are suppressed, regulators tend to have limited information on the economic value of bands; their judgement on the spectrum re-allocations needed is thus made uncertain, and debatable. On the other hand, in any case, regulators' decisions on re-allocations are constrained by the structure of historical rights-of-use; manipulation of these rights (by restricting or transferring them, or by charging for them) is bound to be felt by incumbent operators as unfair—an *ex-post* modification of terms of use—and to be strongly opposed by them.

As a result, the actual structure of spectrum use tends to be at odds with the efficient one and falls short of the requirement that spectrum bands be allocated to their most valuable uses.

Nor this can be judged to be a minor problem. Proof to this is the auctioning for spectrum bands, as it was first introduced in the United States, and later recurred to in a number of countries and widely in Europe. Such auctioning, which involved the allocation of additional spectrum bands, introduced the principle that operators should pay for spectrum use, and gave evidence, in addition, that payments involved might often be substantial (Prat and Valletti 2001, Morris 2005).

### 3.- Spectrum scarcity or spectrum abundance?

Although the electromagnetic spectrum is boundless and radio frequencies account for a vast bandwidth, spanning from around 3 kHz to 3000 GHz, frequencies are not perfect substitutes:

lower frequencies—particularly up to 3 GHz—are usually the most valuable ones for commercial purposes, because they have the most suitable propagation properties for many commercial services, in particular in terms of coverage and power requirements, thus saving on costs (Cave and Webb 2003a). In fact, even if a large part of the radio spectrum is available for exploitation—and attempts to use it have been made, sometimes successfully (e.g., wireless local loop licences are usually for the frequencies in the 26 GHz band and tests in other higher bands, such as the 41 GHz band, have been considered by the industry)—, this is usually frustrated by the (much) higher costs involved with usage of frequencies in the higher swaths of the spectrum, for instance because more antennas need to be deployed, or higher power levels have to be used for communications (thus increasing the occurrence of harmful interference among users).

Therefore, one group of determinants of spectrum scarcity are absolute and relative technological constraints on frequency exploitation. Indeed, on the one hand, there are radio frequencies that cannot be used because we simply (still) lack the technology to do it (i.e., frequencies above 100 GHz); whereas, on the other hand, new technology is available to transmit in currently unused bandwidth—or to exploit further old bands (by means of frequency re-use)—, but it has not become marketable yet (because, for instance, it is too expensive or it cannot be implemented on user-friendly devices).

Nevertheless, as technology has evolved, regulators have not been successful at managing spectrum by means of the legacy formula of command and control (Faulhaber and Farber, 2002) and issues of artificial scarcity have been brought about by defective regulation. For instance, in his independent review for the British government, Cave argues that interference management has emerged as "the key factor rendering the radio spectrum a scarce resource" (Cave 2002: 75).

Indeed, regulation can have an impact on spectrum scarcity in different ways: firstly, scarcity can result because insufficient bandwidth has been made available to particular producers of spectrum-based services, even if suitable frequencies could be available. This is the case, for instance, if parts of the radio spectrum are not allocated to any application or if previously allocated frequencies have been handed back to the regulator, but this has not re-allocated or re-assigned them. Secondly, scarcity can be the outcome of poorly regulated access to spectrum due to insufficient flexibility in the design of licences and spectrum usage rights. In fact, licences issued by national regulators may, for instance, include clauses that prevent sharing of frequencies (between the licensee and other users); or secondary trading of frequencies may be void, likely because command-and-control regulation struggles to accommodate trading arrangements between spectrum users (Bykowsky 2003), that would also limit regulatory discretion to assign rights (Hazlett 1997, Farquhar and Fitzgerald 2003); moreover, "emphasis in existing management systems on minimising interference of all types and at all times may be creating unnecessary spectrum scarcity in the most attractive frequency bands" (Analysys *et alii* 2004: 16), particularly in refraining from a more liberal approach to spectrum management by means of allowing change of its use. Thus, valuable spectrum resources are left idle or put in the (tied) hands of licensees by regulator fiat[1]. But there is also another relevant way in which regulation can contribute to (artificial) scarcity: in fact, the latter depends, indirectly but still notably, on the regulatory environment wherein new technology can develop—thus helping or otherwise preventing research and development of ways to reduce scarcity[2] and use spectrum efficiently.

## 4.- Spectrum management and technological change: a conundrum for command-and-control regulators

The command-and-control approach to spectrum regulation requires a deliberative process (involving study and opportunities for public comment) in order to change allocation of spectrum. This process is very often carried out relying on consultations initiated by regulators on specific issues and there are also instances where the regulators decide to seek support not only by consultants, but also directly by regulatees, sometimes joined in consortia. As a matter of fact, regulatory agencies lack information about the object of regulation and its complexities. However, *ex-ante* regulation of new technologies that have not yet appeared on

[1] Notably, in its recent design of licences for wireless broadband services in the 2010-2025 MHz band, the Australian regulator has stated that "licences are a tradeable, technology-flexible spectrum access right for a fixed term. This means that the licence is not limited to any particular technology, system or service. Instead of authorising the use of a specific radiocommunications device at a fixed site, spectrum licences give licensees the freedom to deploy devices anywhere within their licence area. However, the devices must be compatible with the core conditions of the licence and the technical framework for the band" (ACMA 2006a).

[2] For instance, Faulhaber and Farber (2002) argue—*inter alia*—that, given broadcasters' abundant swath of spectrum for analogue television, there has been a lack of incentives to deploy better filters in televion sets and, thereby, use frequencies more efficiently.

the market is a burdensome and tricky issue that might lead to regulatory failures, should regulation pick the wrong option among those potentially available. A crucial aspect is that regulatory decisions need to be made while new technologies are in their (early) development stage and before they enter the market for commercial deployment.

A number of new tecnologies have been developed recently[3] and many of them promise to enable innovative systems and applications, thus bringing valuable goods and services along the value chain of spectrum (Cave 2006). However, these technologies are still mostly confined in the area of R&D and only few prototypes or first-generation applications have made their way onto the market for commercial use, after many years of scrutiny and tests.

Nevertheless, under the command-and-control formula, it is the regulators' task to anticipate how these technologies should be used to obtain the greatest benefits from overall spectrum exploitation. Also, new technologies can support or require new methods for spectrum management. These tasks imply that regulators need to be aware of emerging technologies, of their potential applications and evaluate whether regulatory action needs to be undertaken.

Thus, regulators are now dealing with the issues that technological developments—such as spread spectrum technologies, dynamic spectrum access technologies, (ad hoc) mesh networking and smart antennas—are raising for spectrum management. In fact, some of these technologies will enable a higher level of spectrum use (e.g., ultra-wideband), other technologies will improve the ability to transmit and receive signals (e.g., smart antennas), and software defined radio technologies might even lead to a state where regulation is no longer needed, because cognitive radios will be able to manage communications autonomously.

But how regulation should change to accommodate these technologies remains controversial. For instance, OFDM[4] allows spectrum sculpting and, therefore, is in principle suitable for use as a spectrum overlay technique; multi-band OFDM (a variant of ultra-wideband) has a

[3] To mention only a few: multi-band OFDM, UWB, MIMO/smart antennas, metamaterial antennas, software defined radios, data compression, turbo coding, inteference cancellation, mesh networks and sensors. Systems implementing these new technologies include 3G/4G communications, WiFi and WiMax, RFID, DVB-H, Flarion, Bluetooth and sensor networks. Examples of applications are mobile phone calls and mobile TV, inventory tracking, PAN, fixed internet access and network backhaul.
[4] Orthogonal Frequency Division Multiplexing.

spectrum sharing feature; ultra-wideband (UWB) enables to use spectrum below the noise-floor; advanced antennas can increase coverage and capacity; last, but not least, mesh networks[5] have a potential to carry out autonomous operations by deploying low power devices and cognitive radio technology in the node terminal equipment.

There is a number of high profile technologies and related applications that do not give rise to regulatory concerns, either because policy implications are now well understood (e.g., UWB) or because they are primarily a cost saving device for network operators with little regulatory impact (e.g., smart antennas). Also, some applications are already well established in the market (e.g., WiFi), whereas others are still too ill-defined and too far into the future to call for regulatory scrutiny (e.g., 4G).

However, as of the moment, new developments that seem to be rather challenging for regulators are software defined radios and (ad hoc) mesh networks.

Software defined radios (SDRs) are dynamic spectrum access technologies, hence the set of transmission parameters is not fixeed beforehand, but it can be chosen and changed dynamically. The crucial difference between SDRs and legacy dynamic spectrum access mechanisms—such as automatic radio frequency selection or vacant channel measurement in DECT cordless communication systems—lies in the fact that these legacy mechanisms involve only unilateral coordination, whereas SDRs involve multi-lateral coordination. Software defined radio devices promise to be able to adapt to their spectrum environment (e.g., channels and modulations schemes) and to new standards, which can be easily implemented by software updates because a great deal of activities that were traditionally performed at hardware level are performed by software in SDRs. However, command and control poses on regulation the burden of a few crucial problems. When will these technologies become marketable?[6] What can be done to prevent intentional or unintentional software modifications (causing unwanted harmful interference)?

Mesh networking is already deployed in fixed wireless access systems, where devices are combined in a structured architecture. However, mesh networks do not increase capacity and

[5] Mesh networks work by relaying data from node to node, rather than sending it back to a radio base station.
[6] SDRs pose a relevant issue of cost-effectiveness, in particular compared with more traditional cellular systems.

do not scale[7], hence do not offer higher spectrum efficiency compared to conventional systems such as cellular. Ad hoc mesh networks might provide increased flexibility by means of their ability to re-route transmissions along different paths, depending on the availability of other nodes within radio range. For example, mesh networks might be deployed to trasmit in under-used swaths of spectrum (e.g., in the 5-6 GHz frequency band), as well as in niche applications (e.g., home automation) or specific situations (such as emergency). Moreover, some applications might require a separate spectrum allocation. Thus, regulatory bodies are required to anticipate the potential impact of such new technology and decide what spectrum environment is desirable. Actually, (ad hoc) mesh networking does not seem to call for further regulatory action[8].

## 5.- Spectrum regulation in Italy—A digression

The problems of command-and-control regulation are neatly illustrated by some recent developments that have occurred in Italy: the switchover from analogue to digital technology in TV broadcasting; the slow take-off of WiMax; the re-allocation of spectrum bands.

### *5.1.- Switch-over and digital dividend in TV broadcasting: how to liberalise spectrum without opening markets to competition*

The use of spectrum for TV broadcasting has always been characterized by features that make the Italian experience a peculiar one, indeed a *unicum* in Europe. About thirty years ago a battle for frequencies kicked off, with (analogue) broadcasters running to occupy frequencies as fast as possible in order to preempt spectrum. This has lead to a situation that has been dubbed "far west" by some commentators, who point out—*inter alia*—that even national regulators struggle to get a clear picture of actual assignment of broadcasting frequencies. However, Agcom is currently trying to map the use of frequencies and build a database[9].

---

[7] Scalability and capacity might be improved in a hierarchical structure.

[8] Actually, (ad hoc) mesh networking is a specific utilization of low power devices and cognitive radio technology (i.e. high-level SDRs, capable of intelligent behaviour in organizing radio communications); therefore, on the one hand, it requires little or no operator intervention and, on the other hand, it is generally associated to licence-exempt operations; hence it does not pose additional spectrum management issues.

[9] Agcom`s work is expected to be carried on at least until the beginning of 2007. Apparently there are some 20.000 Italian TV bases that are not registered according to the international regulations of Stockholm adopted in 1961.

This lack of an initially centralized approach to spectrum management in the Italian broadcasting industry has generated two major market failures in the era of analogue TV broadcasting: it has resulted in spectrum congestion and harmful interference, and it has lead to a duopoly, where two firms—Rai Radiotelevisione s.p.a. and RTI s.p.a. —hold over 10.000 frequencies altoghether, which represent 80% of total frequencies currently available for analogue TV broadcasting nationwide (Agcom 2006a: para. 280).

In 1998, Agcom tried to step into the market by adopting the national table of frequency allocation for analogue TV broadcasting[10]—something that other European states made many years earlier—, but this regulation was not implemented. Also, whereas other European regulators have pursued provision of broadcast content by indenpendent firms (e.g., in the UK, France and Spain), vertical integration of network/frequency owners and content providers has been the dominant market structure in Italy, hence raising antitrust concerns (Agcm 2002, 2004, 2006; Adda and Ottaviani 2005).

These problematic features of TV broadcasting might have been tackled by the advent of digital terrestrial TV (DTT). Digitization of signals allows broadcasting of 4 to 6 TV programmes in the same spectrum swath where analogue broadcast could only accommodate one single programme. Thus, a TV programme that used one unit of allocated spectrum, with digital technology only needs a fraction of input[11]. Therefore, the remainder prime spectrum—the so called digital dividend—is potentially freed-up and can be used to deliver additional programmes (the number depends on image resolution and size, i.e. on the amount of information to be broadcast) or other services (e.g., mobile communications, as well as unlicensed services). Hence, new undertakings may access the digital dividend.

The European Commission, in its communication of 24th May 2005 on "accelerating the transition from analogue to digital broadcasting" (EC 2005b), set out the Community policy objectives for the switchover, identified spectrum gains as one of the major advantage and

[10] The table allocated 51 frequency channels (6 channels in band III VHF and 45 channels in bands UHF IV and V). It also acknowledged 17 TV programmes, with 11 nationwide broadcast programmes and 6 local broadcast programmes (Agcom 2006a: para. 117-8).

[11] "If analogue TV broadcasting is switched to digital transmission [...] three to six times less radio spectrum will be needed. This means that some 300 to 375 MHz of the current amount allocated to terrestrial broadcasting could be freed and become newly available" (EC 2005b: 4)

claimed that “it will be important to not constrain unduly the re-use of these bands for new and innovative services” (p. 7), to provide the most value to society and the economy. This is of particular relevance for those countries (such as Italy, France, Spain and Greece) where terrestrial TV broadcasting has been the dominant technology (whereas other countries, such as Germany, Belgium, the Netherlands and Scandinavian countries have developed cable TV). Furthermore, the Commission contended that the success of digital switchover will be enhanced by effective competition in digital broadcasting transmission services, therefore advocating action by NRAs to ensure that undertakings with significant market power in markets for digital broadcasting transmission are subject to appropriate obligations.

Italy was rather quick in getting the transition started. This began with Law no. 66 of 2001, which set the switch-off by December 2006, although at the end of December 2005 this deadline was moved onwards to 2008. Law no. 66 introduced broadcast infrastructure/frequency trading to allow tests of digital switch-over, therefore opening spectrum management to liberalisation. In fact, frequency trading is still high on the European Commission’s agenda, and only a few countries worldwide have introduced secondary trading of frequencies over the last few years (e.g., the US, the UK, Germany, Australia and Guatemala)[12].

Law no. 66 intended to promote digital switch-over in the frequencies used for terrestial TV, therefore allowing purchase of existing (pieces of) networks by firms interested in starting off tests in digital transmissions. However, Law no. 66 allowed purchase of infrastructure/frequencies only by those broadcasters who had already an authorisation to provide the same kind of service, hence blocking entry by new competitors. Thereby, a second “battle for frequencies” began, with incumbents buying out frequencies used (or left idle) by analogue broadcasters (usually local ones), who are leaving the market as the switch-off of analogue TV is approaching, for instance because of a financial contraint. According to national estimations reported by Agcom (2006a: para. 182), the average cost to be incurred in order to switch analogue plants to digital transmission is likely to be in the range of 300 K € for those with great area coverage, whereas national operators have estimated in around 30-40 Mio € the deployment of a digital network (of 100-150 sites/frequencies) to broadcast digital

[12] However, trading is often permitted in some frequencies only.

terrestrial television in an area where 80% of the population is able to receive the programmes[13].

However, switch-off will not take place soon and a different regulatory path might have been chosen. For instance, it would have been useful to map spectrum usage in advance, in order to get information on spectrum usage before allowing secondary tradings. Also, much of the spectrum in nearby frequency bands is held by the public sector, in particular by the Ministry of defence. Negotiations for spectrum refarming might have been carried out between the Ministry of communications and the Ministry of defence, to arrange for digital switch-over in a way similar to that adopted in the US by the FCC, where, firstly, portions of spectrum have been temporarily allocated to incumbent analogue broadcasters to carry on their operations until migration to digital TV and, secondly, the digital dividend will be auctioned off, hence also opening spectrum to new undertakings (Wik Consult 2005)[14].

Also, Law no. 249 of 1997 firstly set at 20% the maximum amount of analogue networks and programmes that could be broadcast by the same undertaking using terrestrial frequencies and, secondly, set an obligation for incumbents whose operations exceeded such limit to migrate their operations to satellite and cable—within a period of time to be decided by Agcom—in order to conform to the new antitrust limit. Thereby, spectrum could have been freed-up and then made available during the migration from analogue to digital TV (Agcm 2002) [15].

### *5.2.- WiMax systems: how to regulate lagging behind technological development*

WiMax is a new wireless system standard with a wide range of possible operating frequencies. WiMax can transmit signals as far as around 50 Km and has greater throughput (hundreds of Mbps) compared to other wireless systems. Hence, it supports a number of applications,

[13] ITMedia Consulting estimates the value of a frequency (i.e. a programme) that covers 95% of the population in the range of 240-270 Mio €, and an increase in the value per viewer from 1 € (at the introduction of frequency trading by Law no. 66) to 5 €; also, they argue that some 25 multiplexes (i.e. 7 more than those included in Agcom's digital frequency plan of 2003) can operate, thereby leading to a total estimation of DTT frequency of 6 Bio € (Corriere della Sera, 13th February 2006).

[14] Some of the digital dividend will be used for public safety and particularly to facilitate interoperability among public safety organisations. In other countries, regulators are currently deciding how to re-allocate the digital dividend (e.g., Australia and New Zealand). In addition, the UK is auctioning off spectrum, whereas in some countries frequencies are not scarce and, therefore, no options are being considered (e.g., Canada). See Wik Consult (2005).

[15] It was also suggested to sell some of the spectrum controlled by the Ministry of defence to mobile operators, then use these funds partly to compensate the Ministry and partly to subsidize a migration of broadcasters` backhaul services from prime radio spectrum to satellite and fiber (Sole 24 Ore, 18th May 2006).

including fixed consumer and business broadband, backhaul (e.g., for WiFi hotspots) and mobile data services to handsets. Many deployment architectures are possible, but it is primarly based on the same architecture as 2G/3G.

This new system struggles to come onto the Italian market, whereas in other European countries (such as the Netherlands, Germany and Belgium, as well as outside Europe) WiMax has already been developed to provide both business and household wireless services. In Europe, WiMax systems have been developed to be able to operate in the frequency bands 3.4-3.6 GHz and 5.725-5.825 GHz, although the standard can be accommodated throughout the frequency range between 2 and 11 GHz. In July 2005 the Italian Ministry of communications has authorised WiMax tests in a number of Italian geographic locations[16], eventually meeting manufacturers' repeated requests to be able to run tests of systems implementing the new standard. Actually, for a few years Agcom has asked the Ministry of communications to take actions in order to vacate the relevant swaths of spectrum, which are mainly held by the Ministry of defence for its own operations. However, the Ministry of defence is still controlling those frequencies being used to test WiMax and, while the Ministry of communications has been carrying forward the deadline to complete tests (presumably in the hope to find, in the meantime, an agreement with the Ministry of defence), Agcom has recently contended that this situation has become unacceptable and has advocated urgent action by the government (Agcom 2006b: 9)[17].

Vacating the spectrum where WiMax can operate is costly, as the Ministery of defence will have to move its operations (mainly fixed radio communication services) to other sites and frequencies[18]. Also, the Ministry might want to receive compensation (part of the revenues that the government is likely to receive when the spectrum will be auctioned off). Actually, whereas WiFi developed in unlicensed spectrum, WiMax service providers are looking for

[16] See http://wimax.fub.it/. WiMax tests are managed by the Ministry of communications in partnership with Fondazione Ugo Bordoni.

[17] "In questo contesto è inaccettabile il ritardo nella diffusione della tecnologia radio di accesso a banda larga denominata WiMax, dipendente essenzialmente dal continuo differimento nella messa a disposizione della relativa banda di frequenza da parte dell'attuale detentore [il Ministero della difesa].
Auspichiamo che il Governo, assecondando l'impegno del Ministro Gentiloni, sblocchi finalmente questa situazione, consentendo l'assegnazione delle frequenze per il WiMax.
Più in generale, in linea con l'orientamento comunitario, è necessario un ripensamento profondo della politica di ripartizione dello spettro fra gli utilizzatori nel senso di prevedere una vera liberalizzazione dell'uso delle frequenze radio; il che tra l'altro comporterebbe un apprezzabile introito per lo Stato" (Agcom 2006b: 9).

[18] There are also 20 MHz in the 1.8 GHz band that could be made available for electronic communications, but, again, they should be vacated by the Ministry of defence.

licensed spectrum to offer better service quality to their customers (while lower quality—and cheaper—services could be offered in unlicensed frequencies, likely those at 5.725-5.825 GHz ). Moreover, Italian regulators will have to adopt a regulation on spectrum allocation in order to change use of the frequncy bands currently occupied by the Ministry of defence. Indeed, European countries that pioneered commercial development of WiMax systems are those where old licences (issued for mobile services, but left unused and, sometimes, handed back to the regulator) could be re-used to deploy WiMax networks. Hence, flexibility in the use of spectrum was crucial.

*5.3.- Assignment of spectrum for mobile services: how to leave valuable spectrum idle*

Frequencies allocated for mobile services provide two domestic examples that suggest that regulation of spectrum use by command-and-control can lead to delays in the assignment of useful frequencies to market players. Delays are due to the regulatory process governing spectrum management, which could be improved if a more flexible approach—based on private property of frequencies—is introduced.

Firstly, at the end of 2005, 5 MHz of prime spectrum in the 900 MHz band became available following switch-off of Tacs mobile phones. This little amount of spectrum is in high demand because it enables better communications indoors and requires a lower number of antennas to cover the same area.

Secondly, it was only at the beginning of 2006 that the Ministry of communications claimed back the frequencies that were assigned to the mobile operator Ipse during the auction of Umts licences (Prat and Valletti 2001). Ipse has never used the 15 MHz of frequencies won in the auction. These 15 MHz of spectrum cost Ipse around 3.3 billions €; however, Ipse has not complied with its contractual obligations and has engaged in a legal action to obtain a discount on its obligations in order to avoid bankruptcy. Although attempts to re-assign these frequencies to the other winners in the auction (Tim, Vodafone, Wind and H3G) have been pursued by the government, negotiations among these mobile operators failed.

Notwithstanding demand for these frequencies (as well as for those that the Ministry of defence is expected to vacate), national regulators are still in the process of deciding how to re-assign frequencies (ie, whether to choose a beauty contest or an auction). Meanwhile, valuable spectrum has been left idle.

## 6.- Alternatives to command-and-control regulation, or, why a market regime should be preferred to a commons regime

Reform of the approach to spectrum management is opposed by embedded interests (not only of incumbent firms providing spectrum-based services, but also of regulators—including some of those who have engaged in the discussion on spectrum management reform—, as their role would be at least diminished both by a commons or a market regime). The literature, however, offers a different view: command-and-control regulation is defective (at least in the way it is conceived presently) and a change in spectrum regulation is urgently needed[19].

However, firstly, there is considerable disagreement on the direction that spectrum reform should follow and, secondly, elaboration of a viable spectrum management regime—alternative to command and control—is still at an early stage. Notably, in its communication on the review of EU regulatory framework for electronic communications networks and services, the European Commission has stated that

> "[a] new system for spectrum management is needed that permits different models of spectrum licensing (the traditional administrative, unlicensed and new marked-based approaches) to coexist so as to promote economic and technical efficiency in the use of this valuable resource. Based on common EU rules, greater flexibility in spectrum management could be introduced by strengthening the use of general authorisations whenever possible" (EC 2006: 7).

Whether a new spectrum strategy should be guided by market mechanisms or by the commons paradigm has been a controversial issue for many years, in particular in the US. Also, in early stages of this controversy, there was a rather clear-cut opposition between those who supported the introduction of wide-spread market mechanisms—usually economists, advocates of the magic of the market—and those who supported the commons formula—

[19] See, for example, Coase (1959), Noam (1998), Hazlett (1998), Benkler (2002), Cave (2002), FCC (2002), Faulhaber and Farber (2002), Kwerel and Willams (2002), Benjamin (2003), Faulhaber (2005), EC (2005b), Ofcom (2005a) and Baumol and Robyn (2006). A plea for a change of spectrum regulation in Italy is contemplated in Agcom (2006b).

usually legal scholars and some technocrats, advocates of the magic of hardware (Faulhaber 2006). Thereby, while “economists, following Ronald Coase, have favoured placing all licences into the market, permitting both private and public licensees to buy, sell, trade, aggregate, and disaggregate spectrum rights, in a manner unfettered by government-imposed use restrictions”, their opponents point to new wireless technologies and argue in favour of a commons in spectrum with no property rights (Faulhaber 2006: 539).

Recently, the discussion in the literature has lost some of its conflicting features and the idea has been advanced that both market mechanisms and commons arrangements can prove useful in the design of a renewed approach to spectrum management. However, profound differences still remain regarding what should be the right mix of the two: whereas some believe that regulation should move towards more flexibility by reliance on market mechanisms, with forms of commons for only parts of the spectrum (Ofcom 2005a, Baumol and Robyn 2006, Faulhaber 2006), others believe that spectrum management should be based on a commons approach, with some market mechanisms in specific instances (Benkler 2002, Werbach 2004).

Indeed new technology and recent applications have been used by supporters of the latter view to put forward their case for a commons-based approach. Developments in spread spectrum technologies (which allow higher levels of spectrum usage by transmitting over a much wider range of frequencies compared with legacy technologies), the fast growth of WiFi applications (which provide wireless broadband access to data networks) and the promises of cognitive radios (with their capabilities to sense the surrounding environment and intelligently select the appropriate behaviour) have been used by advocates of the commons to argue against licensed spectrum and market mechanisms as the basic ingredients of a new approach to substitute for command-and-control regulation.

However, counter arguments can be made to rebuff the belief that a spectrum commons should be the way forward. In fact, spread spectrum technologies are often underlay techniques[20],which operate across licensed bands enabling operations by secondary users on a

[20] Spectrum underlay techniques seek coexistence between two or more users of the same channel (or spectrum swath) by enabling transmissions with very low power by secondary users that will not interfere with systems with higher power densities deployed by a primary user. Spectrum overlay techniques are based on a intrude-

no-harmful interference basis; WiMax applications, which may be regarded as advanced WiFi ones (enabling faster connections over longer distances), are being developed within a framework of exclusive use of frequencies[21]; also, the promises of cognitive radios are still a long way ahead in the future and it is all but clear how self coordination of complex independent devices will actually take place in a spectrum commons.

Also, it might happen that, in the future, technological development will bring about marketable devices that can intelligently organize communications among them and, by means of such capabilities, use the spectrum without causing reciprocal harmful interference; however, this is a scenario still very far from what is allowed by hardware and software available today. Indeed, advocates of a commons approach have not yet provided a viable solution to the problem of coordination that has to be solved in a spectrum commons to avoid harmful interference. Whilst the theory offers mechanisms to tackle this issue—an example is the Clarke-Groves mechanism[22]—ways to implement them in practice have not been found yet (Cave 2006). In addition, reliance on development of social norms suggested by game theoretical studies are, according to Faulhaber (2005: 30), "romantic but fanciful". Contributions from game theory assume stable communities in which actions among players are part of a pattern of a repeated game[23]. In wireless communications, a multitude of users might transmit in the same frequencies and mobility is crucial; therefore, only very few homogeneous groups can be seen as players in a repeated game (e.g., amateur radio operators) and cooperation is unlikely to occur. Moreover, Mahoney and Sachirico (2003) suggest that, if the cooperative equilibria require investments, it is likely that they will be unstable compared to non-cooperative equilibria[24].

Nevertheless, the concept of a commons is not to be rejected altogether. Actually, whereas it is fanciful to believe that a commons can take over spectrum management based on the command-and-control formula (and perform better), parts of the spectrum may be used as a

---

and-avoid principle such that a secondary user transmits signals only when the channel is not occupied by the primary user.

[21] Notably, WiFi networks utilize unlicensed frequencies. However, access is usually limited to authorized persons or provided to users who pay for access to the network over an agreed period of time (e.g., one month).

[22] See Analysys *et alii* (2004). The Clarke-Groves mechanism is based on the feature that any respondent whose reported evaluation of the public good tips the decision to buy into the positive has herself to pay a surcharge equal to the difference between all other participants' preference for the alternative option. The mechanism is reviewed in Campbell (2005: 283-294); see also Groves Ledyard (1977).

[23] See, for example, Eatwell *et alii* (1989), Fudenberg and Tirole (1991) and Osborne (2004).

[24] See Faulhaber (2005: 30) for details on this argument based on contributions from game theory.

commons. However, a commons regime for some frequency bands should not be arranged—or, indeed, interpreted—as open access to those frequencies. Open access to valuable (scarce) spectrum would lead to what has been called—paraphrasing Garret Hardin's tragedy of the commons—a spectrum tragedy (Hazlett 2005); too many users seeking access to the same resource would eventually end up causing each other harmful interference and blocking transmissions altogether. Open access would bring about exactly what the introduction of spectrum regulation intended to avoid and control: chaos in the ether (Coase 1959, Hazlett 2001). Ultimately, open access implies that spectrum belongs to nobody and is also beyond end-state regulation:

"[o]pen access regimes reflect the unwillingness or inability of the government, society or current users to introduce and enforce an effective system of control that determines the total number of users and regulates the behaviour of insiders. Two functions that all systems of property rights share, exclusion and governance, are missing from open access regimes. When exclusion and governance are absent, economic agents lack the incentive to economize in the use of resources, maintain their quality, and invest in their improvement.
In marginal cases, such behaviour is economically efficient, namely when the costs of effective exclusion and governance are high relative to the value of resource units" (Eggersson 2003: 85-6).

As we have been arguing, spectrum—and particularly frequencies in high demand—cannot be regarded as one of the marginal cases where open access may be justified on economic grounds. And actually open access is different from a commons: a commons has an owner (or is owned by a group), therefore the tragedies associated with open access can be avoided, since it will be for the owners to regulate use of their resource in order to avoid inefficiencies (Ostrom 1990). Indeed, spectrum governed by a commons regime can be disciplined by market forces: the owner(s)—both private and public—can buy, sell, trade, aggregate and disaggregate her (their) spectrum rights. Should market forces require more frequencies to be accessed by a plurality of users—authorized by the owner(s) of the commons, if spectrum is not used directly by the latter—the allocation of the resources of the spectrum will occur on the basis of a mechanism that is likely to warrant an efficient outcome. Instead, should the commons formula be less efficient (for the whole swath of spectrum, or only for a part of it) compared to an alternative arrangement, the market will re-allocate that spectrum to the party that values it the most.

And whereas Kwerel and Williams (2002), advocating market mechanisms for spectrum management, have suggested a big-bang auction of all spectrum, advocates of an open access regime (usually, and misleading, defined “a commons”) have not made proposals on how to abandon the current formula of command and control and move to their envisioned scenario. Thereby, on the one hand, there are ways to move forward in regulating spectrum more efficiently within the property rights paradigm, but, on the other hand, no such pragmatic guidance has emerged with regard to other paradigms.

However, a phased approach towards a spectrum management regime based on exclusive property rights seems a more viable option (Ofcom 2005a, Cave 2006). Until a systematic approach to spectrum strategy will not eventually be implemented—and we have been arguing that a property rights regime is to be preferred to a commons—inefficiencies in spectrum management are likely to be persistent.

## 7.- Towards a new spectrum strategy

In the past, relatively slow technological change, and relatively abundant spectrum availability concurred to keep inefficiencies of command-and-control regulation small, or tolerable. Over the years, regulators have tried to cope with (increasing) technological change and (booming) demand in wireless communications by adjusting, in dribs and drabs, allocation of frequiences; they have also established procedures to change spectrum assignment, usually involving vacation of frequencies operated by the previous user and subsequent re-assignment to another user, by means of either a “first-come, first-served” procedure, or, in case of excess demand, a “beauty contest” (or even a lottery, which, paradoxically, in trying to get rid of regulatory discretion in the allocation of frequencies, results in the most inefficient outcome).

With auctions—an option first advocated by Coase in 1959, immediately rebuffed by the FCC as a “big joke”, but eventually espoused by regulators fifteen years ago (Hazlett 2001)—command and control has opened to market mechanisms in primary frequency assignment; later on, some regulators have also introduced frequency trading secondary frequency assignment (Wik Consult 2005), hence providing a means to let the market move spectrum from one user to another.

However, on the one hand, spectrum trading—without liberalization of frequency use (Hazlett 2003)—does not solve the problem of regulatory mis-allocation of frequencies (Valletti 2001, Analysys *et alii* 2004); on the other hand, in those countries where licences can be traded, only a limited number of trades has taken place, and often among firms under the same parent company (Wik Consult 2005).

There are at least two likely lines of reasoning for such observation (which, however, call for further research): firstly, trades may be very few because incumbent licence holders do not wish to risk increased competition by trading in their spectrum usage rights; secondly, the small number of trades may be given by poorly defined spectrum usage rights, particularly in that such rights can only be (partially) transfered by one user to another, without change of use.

In the first case, if a different market structure is desirable, the instruments of antitrust regulation can be triggered (Cave 2002, Ofcom 2005a). Nevertheless, changes in the spectrum management regime might also help. In the US, "easements" have been suggested (Faulhaber and Farber 2005) to enable secondary users to transmit in the frequencies of a licensed user, provided that the latter do not suffer any harmful interferences (and, thus, losses). For instance, easements might be useful for applications based on ultra-wideband technology (which transmit below the noise floor) or for those spectrum-based services that do not require time-continuous availability of frequencies (e.g., data-intensive applications). While easements in spectrum use might be easily introduced (either by simply modifying existing licences or by re-issuing them) and might also accommodate, substantially, the instances of the advocates of a commons for spectrum resources (Faulhaber and Farber 2005), this novel arrangement would be very much crafted in the existing framework of command and control; in particular, it is far from clear how "a governmental rule without price and profit incentives will be able to match the performance of a market regime" (Baumol and Robyn 2006: 62).

To develop a full-fledged (secondary) market, both cases need regulation to properly define and allocate spectrum usage rights. Regulation has two main options. The first option would be to virtually re-issue all existing licences, by transforming them in spectrum property rights—designed around only a few crucial features of spectrum usage—, and then letting Coasian bargaining find the optimal configuration of such rights. This option would favour the *status quo* and likely save on transaction costs. The second option would be a more radical change to a property rights regime, where all licences are withdrawn and entitlements to the same bundle of property rights (i.e., spectrum usage features) are granted to all previous licensees. However, on the one hand, this would bring about issues of redistribution of difficult solution (Kwerel and Williams 2002) and, on the other hand, transaction costs to adjust the "one-does-not-fit-all" bundle of rights (initially issued by the regulator) are likely to be very high and even block bargaining. Hence, the initial decision on the configuration of spectrum usage rights is crucial and regulators elaborate the (approximately) correct bundle of rights (Cave and Webb 2003b).

A few regulators—particularly in Australia and the UK—have taken significant steps in this direction. In Australia, property rights in spectrum have already been introduced (PC 2002) rather successfully, as only few issues of interference among users have arised (Wik Consult 2005). However, some users have contended that the regulatory decision tends to lend spectrum to particular applications, thereby failing to meet service neutrality and advocating further flexibility to change current arrangement. Broadly, these arrangements set the maximum transmit power, the maximum adjacent channel (or out-of-band) interference and the maximum out-of-area interference (Cave and Webb 2003b). A similar approach is being pursued in the UK by Ofcom, which, in drawing up spectrum usage rights, is considering three main type of interference, i.e., geographical interference, out-of-band interference and in-band interference (Ofcom 2006).

## 8.- Administrative incentive pricing

The design and implementation of a new spectrum management regime is likely to take considerable time, no matter whether reviews of spectrum strategy will favour a commons or a full-fledged market regime. However, meanwhile, there are ways to promote efficient spectrum use by relying on administrative incentive pricing (AIP), which adopts a market approach and may be quickly introduced.

*8.1- Spectrum charges and administrative incentive pricing*

AIP is based upon economic criteria that seek to identify the economic value of radio spectrum. Indeed, administrative spectrum pricing methodologies attempt to reproduce the market clearing price (CEPT 1999). The underlying rationale is that, in the absence of a well functioning market for spectrum, AIP will (try and) reflect the opportunity cost. This should help ensure that spectrum flows from low to high value uses. Also, as the objective is to price scarce spectrum close to market levels, periodic AIP adjustments are supposed to take account of changing scarcities.

In a study for Ofcom, Indepen *et alii* (2004) suggest that, in deciding whether there are opportunity costs associated with the frequency bands and radio services, the following tests should be applied:

- is there excess demand for spectrum now or in the near future from existing uses?
- can the spectrum be used for another purpose and, if so, is there excess demand from other uses?
- is it practically feasible to collect AIP fees given possible constraints due to avoidance or illegal use?
- are there any policy or political factors that prohibit the use of AIP?

However, in cases where AIP is not appropriate—because the marginal opportunity cost of spectrum is zero—licence fees should be set only to reflect the spectrum management and enforcement costs caused by each service. Therefore, regulators have adopted different financing schemes, which can be sorted in the four following groups: a) a fee-based model; b) a state-financed model; c) a charge-based model with or without a cost-allocation system; and d) hybrid fee and charge-based models (CEPT 2004).

A comparison of the frequency usage fee structures in different countries has revealed that at least a few of the following ten features are generally considered by regulators (Yu *et alii* 2004): frequency bandwidth, emission power, coverage area, frequency band, dedicated use *vs*. shared use, time of use, transmit vs. receive-only use, application/service type, supply *vs*. demand, and special purpose. For instance, in Korea, frequency usage fees are calculated based on a formulation that includes bandwidth, frequency band, (non-) shared use and type of service. In Australia, relevant parameters are bandwidth, area of coverage, geographic and spectrum location. Ofcom (2005b) has recently identified a number of common principles to apply in setting tariffs for licence fees and administrative charges: a) use of turnover as a common tariff basis across all sectors or the setting of fixed tariffs where applicable; b) collection of turnover data for the last but one calendar year; c) implementation of administrative charges and licence fees for each regulatory sector and for each regulatory category within the regulatory sector. This will ensure reduced fees for regulatory categories with lower regulatory costs. Last, but not least, tariffs for some categories, where turnover data is inappropriate, may be set as fixed cash sums.

*8.2.- How to set AIP*

The initial UK work, in attempting to set an administrative price that reflects the marginal opportunity cost, was done by Smith-Nera in the 1996 for the Radiocommunications Agency. This method relied on estimating the change in an operator's costs according to the amount of spectrum that could be used. For example, a GSM operator might need spectrum to increase its capacity in certain urban and suburban areas. It could either do this by having more spectrum, or perhaps reducing cell sizes, or going to half rate codecs. The model would thus attempt to estimate the difference in costs of having extra spectrum, or spending more on infrastructure. This was then refined by the British regulator, which introduced modifiers for the type of land area where the spectrum was used, urban/suburban and rural. However, most of the cost was biased towards the areas where spectrum was scarce (Indepen *et alii* 2004).

This approach was later developed to tackle emerging issues, such as working out the marginal private value for spectrum in a number of likely uses (and not just one). For example, it might be that a given piece of spectrum could be used for PMR, GSM, or fixed links. Thus a marginal value can be calculated based on those three services. It is also possible to calculate the marginal value of using alternative pieces of spectrum for the same service, e.g. GSM use at 900 MHz or 450 MHz. This would then give a table of values that might show that the current use is not associated to the highest value. It would then be for the regulator to decide how to set a price to encourage efficient allocation[25].

[25] The aforementioned work by Indepen *et alii* (2004) suggested that the price be set towards the lower end of the valuations between the higher and lower value services. This would then help to encourage spectrum to flow from low to high value uses.

A further refinement is to ask the question of what happens if the quanta of spectrum can not be altered, whilst keeping the same output. For example in TV broadcasting, an analogue 8 MHz channel is required at a minimum. It may not be possible to use extra infrastructure to reduce this (perhaps because of public service requirements on such broadcasters). In such circumstances it might be required to use a marginal profit analysis. This requires more information, as not only do costs need to be modelled, but also consumer demand. This then is a full blown modelling exercise to calculate the net present value, that would reveal how much the spectrum might go for in an auction.

Other enhancements have also been suggested, such as working out the average between the impact of having more and less spectrum. For example, if one were to take one MHz from a PAMR provider, the difference in extra equipment costs might be € 100,000. If such a PAMR operator were given an extra one MHz, this might have a value of only € 50,000. Thus the efficient AIP could be set at the average of € 100k and $50k (€ 75k).

*8.3.- AIP and the impact of spectrum on costs*[26]

The following table details a typical calculation of AIP, based on the Smith-Nera method. The calculation is very dependent on the initial assumptions chosen, such as discount rates and re-use patterns, as well as the change in spectrum taken into account. In this case it was 2x3 MHz, which requires an extra radio transceiver to be placed at each cell site. This means that in urban areas the cell sizes can increase, and hence the number of sites decreases by 84. The reductions in all the cost associated with these 84 sites is the upside of the AIP calculation. The downside is the extra costs of more radio transceivers.

The model then calculates the two figures, the savings from having 84 sites less (which is possible from having an extra 2x3 MHz) and the extra costs of buying more transceivers. There will be a cost associated with installing these extra transceivers, but it is assumed here the cost is small as aerials normally have extra ports available, and that maintenance cost covers the extra site visits required (to install the extra racks).

The figures arrived at are:

[26] We acknowledge Roberto Ercole's valuable contribution in this part of our paper.

| | | | |
|---|---|---|---|
| For 84 sites | Capital | € 6,720,000 | saved |
| | Annual | € 1,512,000 | saved |
| Extra costs of more trxs to use extra 2x3 MHz | Capital | € 2,520,000 | extra |
| | Annual | € 252,000 | extra |
| Difference | Capital | € 4,200,000 | |
| | Annual | € 1,260,000 | |

The capital figure is annualised over 10 years to give an annual fee of € 663,691 (based on a 12% discount rate). This figure is added to the annual saving of € 1,260,000, to give a total annual AIP charge of € 1,923,691. This is the fee for 2 x 3 MHz of spectrum and, with fifteen 2x200kHz GSM channels, this equates to a fee of € 128,246 each.

*8.4.- Fit for purpose*

AIP has already been applied in a few countries and countries in the process of reviewing overall spectrum pricing policy are considering it. The level of complexity and detail, that is required in any AIP scheme, depends on the policy objectives[27] and on the local market situation. For instance, Australia and New Zealand have allowed for AIP, but because neither country is experiencing significant spectrum scarcity or congestion, it has only been applied to a limited extent within an overall cost recovery framework (ACMA 2006b).

A possible argument against spectrum pricing, in particular amongst public sector users, is that spectrum pricing would simply lead to a recycling of funds between different branches of government. However, Cave (2002) contended that even if the public sector user were to be fully compensated for their spectrum use, then it would still have incentives to reduce usage of spectrum and use the funds made available for other purposes.

[27] According to the ACMA, as fees are set in the context of a political process—they are subject to Ministerial decision—there have been obstacles in making significant revisions to either the overall level of charges or to relative charges. Also, the ACMA does not base its analysis on specific and contestable estimates of opportunity costs, as Ofcom has sought to do.

## 9.- Conclusions

Evidence suggests that command-and-control regulation is no longer a suitable arrangement for spectrum management. Rapid technological development and booming demand for spectrum-based services have made apparent the limits of current regulations, which, even if they might have been useful in the past, do not provide a framework for efficient use of spectrum resources anymore. Indeed, spectrum use should be characterized by a (much) higher degree of flexibility.

However, demise of the formula of command and control is unlikely to happen all of a sudden: the traditional approach to spectrum management cannot be replaced, *ex abrupto*, by neither a commons nor a property rights regime, because there is a number of issues that need to be addressed by regulators, in order to gradually move to a more flexible and effective regime.

This transition should favour market mechanisms and, in particular, it should be implemented by designing spectrum usage rights. Thus, spectrum would be treated like any other input (which users can, for instance, buy, sell or lease) and a full-fledged market could then develop. This implies the withdrawal of regulation, on the one hand, from practices aimed at coping with contingencies and, on the other hand, from the issuing of licences that, in an attempt to (allegedly) avoid harmful interference and to protect the operations of incumbent spectrum users, have caused inefficiencies artificial scarcity of spectrum resources.

While the discussion about (introduction and, then, fine-tuning of) a new regime is on-going, market-based mechanisms to spectrum management might be rapidly adopted. These would not only provide immediate incentives for a more efficient use of spectrum resources, but could smooth the transition to a new market-based regime for spectrum management. In particular, the introduction of administrative incentive pricing for those parts of the spectrum—i.e., the majority—where market mechanisms are not in place (neither for allocation, nor for assignment) could reduce current inefficiencies in spectrum management. However, only a full-fledged market regime, implemented in ways that will minimize transaction costs, is likely to bring about the most relevant gains, particularly by enabling efficient re-allocation of frequencies.

## References

ACMA - Australian Communications and Media Authority (2006a). *Auction of Spectrum Licences for Wireless Broadband Services in the 2010–2025 MHz Band,* MR 86/2006, http://www.acma.gov.au/acmainter.65636:standard::pc=pc_100720.

ACMA - Australian Communications and Media Authority (2006b). *The Apparatus Licence Fee Schedule*, Canberra, ACMA.

Adda J. and Ottaviani M. (2005). "The Transition to Digital Television", *Economic Policy*, vol. 20, no. 41, 160-209.

AGCM – Autorità Garante della Concorrenza e del Mercato (2002). "Assetto del Sistema Radiotelevisivo e della Società RAI – Radio Televisione Italiana", Communication no. AS 247 of 19th December 2002, *Bollettino AGCM*, no. 49/2002.

AGCM – Autorità Garante della Concorrenza e del Mercato (2004). "Indagine Conoscitiva sul Settore Televisivo: la Raccolta Pubblicitaria", Decision no. IC 23 of 16th November 2004, *Bollettino AGCM*, no. 47/2004.

AGCM – Autorità Garante della Concorrenza e del Mercato (2006). "R.T.I.-Reti Televisive Italiane/Ramo di Azienda di Europa TV", Decision no. 15333 of 12th April 2004, *Bollettino AGCM*, no. 1/2006.

AGCOM – Autorità per le Garanzie nelle Comunicazioni (2006a). *Consultazione Pubblica sulla Identificazione ed Analisi del Mercato dei Servizi di Diffusione Radiotelevisiva per la Trasmissione di Contenuti agli Utenti Finali, sulla Valutazione di Sussistenza del Significativo Potere di Mercato per le Imprese Ivi Operanti*, annex B, Decision no. 61/2006/CONS of 1st February 2006, http://www.agcom.it/provv/d_61_06_CONS/d_61_06_CONS.htm.

AGCOM – Autorità per le Garanzie nelle Comunicazioni (2006b). *Relazione Annuale sull'Attività Svolta e sui Programmi di Lavoro*, AGCOM, Roma, July.

Analysys, Dotecon, Hogan and Hartson (2004). *Study on Conditions and Options in Introducing Secondary Trading of Radio Spectrum in the European Community. Final Report for the European Community*, Analysys, Cambridge.

Analysys and Mason (2005). *Spectrum Demand for Non-Government Services 2005-2025. Final Report for the Independent Audit of Spectrum Holdings*, London, Analysys.

Baumol W.J. and D. Robyn (2006). *Toward an Evolutionary Regime for Spectrum Governance*, Washington, D.C., AEI-Brookings Joint Centre for Regulatory Studies.

Benjamin S.M. (2003). "Spectrum Abundance and the Choice between Private and Public Control", *New York University Law Review,* vol. 78, pp. 2007-2102.

Benkler Y. (2002). "Some Economics of Wireless Communications", *Harvard Journal of Law & Technology,* vol. 16, no. 1, 25-83.

Bykowsky M. (2003). "A Secondary Market for the Trading of Spectrum: Promoting Market Liquidity", *Telecommunications Policy,* vol. 27, no. 7, 533-541.

Campbell D.E. (1995). *Incentives: Motivation and the Economics of Information*, Cambridge University Press, Cambridge.

Cave M. (2002). *Review of Radio Spectrum Management. An Independent Review for Department of Trade and Industry and HM Treasury,* London, HM Treasury.

Cave M. (2006). *New Spectrum-Using Technologies and the Future of Spectrum Management: a European Policy Perspective*, forthcoming.

Cave M. and Webb W. (2003a). "Spectrum Licensing and Spectrum Commons: Where to Draw the Line"*, Warwick Business School, papers in spectrum trading no. 2.*

Cave M. and Webb W. (2003b). "Designing Property Rights for the Operation of Spectrum Markets"*, Warwick Business School, papers in spectrum trading no. 1.*

CEPT – Conférence Européenne des Administrations des Postes et des Télécommunications (1999). *The role of spectrum pricing as a means of supporting spectrum management*, Marbella, CEPT.

CEPT – Conférence Européenne des Administrations des Postes et des Télécommunications (2004). *Cost Allocation and Accounting Systems Used to Finance the Radio Administration in CEPT Countries*, ECC Report 53, Dublin, CEPT.

Coase, R.H. (1959). "The Federal Communications Commission", *Journal of Law and Economics,* vol. 2, no. 1, 1-40.

Coase, R.H. (1960). "The Problem of Social Cost", *Journal of Law and Economics*, vol. 3, pp. 1-44.

Eatwell J., Milgate M. and Newman P. (eds) (1989). *The new Palgrave: Game theory*, London, W.W. Norton.

EC - European Commission (2005a). *A Forward-looking Radio Spectrum Policy for the European Union: Second Annual Report*, Communication of 6th September 2005, Bruxelles, European Commission.

EC – European Commission (2005b). *Accelerating the Transition from Analogue to Digital Broadcasting*, Communication of 24th May 2005, COM(2005)204, Bruxelles, European Commission.

EC - European Commission (2006). *Review of EU Regulatory Framework for electronic communications networks and services*, Communication of 29th June 2006, Bruxelles, European Commission.

Eggertsson T. (2003). "Open Access versus Common Property" in *Property Rights: Cooperation, Conflict, and Law*, eds. T.L. Anderson and F.S. McChesney, Princeton, Princeton University Press, 73-89.

Ellig J.(2005). *The Economic Costs of Spectrum Misallocation: Evidence from the United States*, paper presented at the conference "Spectrum Policy in Guatemala and Latin America", mimeo.

Farquhar M.C. and Fitzgerald A.Q. (2003). "Legal and Regulatory Issues Regarding Spectrum Rights Trading", *Telecommunications Policy,* vol. 27, no. 7, 527-532.

Faulhaber G.R. (2005). *The Question of Spectrum: Technology, Management, and Regime Change*, Working Paper.

Faulhaber G.R. (2006). "Wireless Telecommunications: Spectrum as a Critical Resource", *Southern California Law Review,* vol. 79, 537-559.

Faulhaber G.R. and Farber D.J. (2002). *Spectrum Management: Property Rights, Markets, and the Commons*, Washington, D.C., AEI-Brookings Joint Centre for Regulatory Studies, working paper 02-12.

FCC - Federal Communications Commission (2002). *Report by the Spectrum Policy Task Force, ET docket no. 02-135.*

Fudenberg D. and Tirole J. (1991). *Game theory,* Cambridge (Mass.), MIT Press.

Groves T. and Ledyard J. (1977). "Optimal Allocation of Public Goods: A Solution to the 'Free Rider' Problem", *Econometrica: Journal of the Econometric Society,* vol. 45, no. 4, 783-810.

Hazlett T.W. (1997). "Physical Scarcity, Rent Seeking, and the First Amendment", *Columbia Law Review,* vol. 97, no. 4, 905-944.

Hazlett T.W. (1998). "Spectrum Flash Dance: Eli Noam's Proposal for 'Open Access' to Radio Waves", *Journal of Law and Economics*, vol. 41, no. 2 (2), 805-820.

Hazlett T.W. (2001). *The Wireless Craze, The Unlimited Bandwidth Myth, The Spectrum Auction Faux Pas, and the Punchline to Ronald Coase's 'Big Joke'. An Essay on Airwave Allocation Policy*, AEI-Brookings Joint Centre for Regulatory Studies, working paper 01-01.

Hazlett T.W. (2003). "Liberalizing US Spectrum Allocation", *Telecommunications Policy,* vol. 27, no. 7, 485-499.

Hazlett T.W. and Muńoz R.E. (2004). *A Welfare Analysis of Spectrum Allocation Policies*, Washington, D.C., AEI-Brookings Joint Centre for Regulatory Studies, working paper 04-18.

Hazlett T.W. (2005). "Spectrum Tragedies", *Yale Journal on Regulation,* vol. 22, no. 2, 243-274.

Indepen, Aegis and Warwick Business School (2004). *An Economic Study to Review Spectrum Pricing*, London, Indepen.

ITU - International Telecommunication Union (2004). *Radio Spectrum Management for a Converging World*, Geneva, ITU.

Kwerel E. and Williams J. (2002). *A Proposal for a Rapid Transition to Market Allocation of Spectrum*, Washington, D.C., FCC - Office of Plans and Policy, working paper n. 38.

Mahoney P.G. and Sanchirico C.W. (2003). "Repeated Games, and the Role for Law", *California Law Review,* vol. 91, no. 5, 1281-1329.

Morris A.C. (2005). "Spectrum Auctions: Distortionary Input Tax or Efficient Revenue Instrument?", *Telecommunications Policy,* vol. 29, no. 9-10, 687-709.

Noam E. (1998). "Spectrum Auctions: Yesterday's Heresy, Today's Orthodoxy, Tomorrow's Anachronism. Taking the Next Step to Open Spectrum Access", *Journal of Law and Economics*, vol. 41, no. 2 (2), 765-790.

Ofcom – Office of Communications (2005a). *Spectrum Framework Review Statement*, London, Ofcom.

Ofcom – Office of Communications (2005b). *Statement of Charging Principles*, London, Ofcom.

Ofcom – Office of Communications (2006). *Spectrum Usage Rights*, London, Ofcom.

Osborne M.J. (2004). *An Introduction to Game Theory,* Oxford, Oxford University Press.

Ostrom E. (1990). *Governing the Commons: the Evolution of Institutions for Collective Action,* Cambridge, Cambridge University Press.

PC – Productivity Commission (2002). *Radiocommunications*, Report no. 22, Canberra, Ausinfo.

Prat A. and Valletti T. (2001). "Spectrum Auctions Versus Beauty Contests: Costs and Benefits", *Rivista di Politica Economica*, vol. 91, no. 4-5, 59-109.

Valletti T.M. (2001). "Spectrum Trading", *Telecommunications Policy,* vol. 25, no. 10-11, 655-670.

Werbach K. (2004). "Supercommons: Toward a Unified Theory of Wireless Communication", *Texas Law Review,* vol. 82, 863-973.

Wik Consult (2005). *Towards More Flexible Spectrum Regulation*, Wik Consult, Bad Honnef, December.

Yu H.C., Lee Z.Y. and Lee H.Y. (2004). "Revising Taiwan's Frequency Usage Fee Regulation", *Telecommunications Policy*, vol. 28, no. 9-10, 679-695.