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Abstract

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 regulatory arrangements for spectrum access and use. Regulators, especially in industrial countries, have taken a number of steps of remedial policy *vis-à-vis* these difficulties, by increasing the share of spectrum made available for commercial use as well as by injecting some flexibility into command-and-control regulation. These are, however, steps of a temporary, palliative nature and do not make for a wider spectrum management reform. Starting from a discussion of the limitations of command-and-control regulation, this paper deals with the two main, alternative approaches which have been proposed: a (Coasian) market regime, and a commons regime. After taking sides in favour of the market regime, consideration is given to some implementation issues, and to a regulatory formula—called administrative incentive pricing—which could help ensure a smooth transition from command-and-control to market arrangements.

JEL classification: K11, L51, L82.
Keywords: Telecommunications policy, Spectrum management, Market mechanisms, Administrative incentive pricing.

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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, "today, 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, pp. 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 *et al.*, 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. 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); they have also injected flexibility into command-and-control regulation, by auctioning spectrum bands, allowing secondary trading (subject to no changes in use), permitting innovative ways of commercial access to spectrum use (e.g. airtime resale, virtual network operation) and widening unrestricted access to spectrum bands (ITU, 2004).

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. And 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 with which economics is familiar, in a considerable number 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), customarily proposed for these kinds of problems, finds considerable support (e.g., Hazlett, 1998, 2003; Kwerel and Williams, 2002; Baumol and Robyn, 2006). But, especially in the American literature, an alternative proposal has been presented, involving the management of spectrum as a commons and limited regulation to avoid harmful radio interference (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 sides 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 regulators allocating (technologically usable and commercially valuable) spectrum bands to users and applications. Regulators usually allocate licensing and exclusive rights; however, in a few cases (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 or guard-bands. Finally, no significant payment is required for access and use.

This approach has large, and well known, efficiency costs (Hazlett and Muñoz, 2004; Ellig, 2005). It is an inherently conservative approach, in a rapidly shifting technological and economic situation. 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, 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, being an *ex-post* modification of the original 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.

This is not a minor problem as has been proved by the auctioning of spectrum bands, introduced in the United States, and later repeated 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 also showed 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, as they have the most suitable propagation properties for many commercial services, in particular in terms of coverage and power requirements; thus they allow saving on costs (Evci and Fino, 2001; Cave and Webb, 2003a). Attempts to use higher frequencies have been made successfully (for instance, 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). But the higher costs usually involved with transmissions in these frequencies make the use of a large part of the radio spectrum unviable: more antennas need to be deployed, or higher power levels have to be used for communications (hence an increase in radio frequency interference).

Therefore technology engenders absolute and relative constraints on frequency exploitation. Indeed, there are radio frequencies that cannot be used because we lack the technology to use them (i.e., frequencies above 100 GHz). And, although, new technology is available to transmit in currently unused bandwidth or to exploit further some bands (by means of frequency re-use), it has not become marketable yet, either because it is too expensive or it cannot be implemented on user-friendly devices.

Radio technology is subject to rapid change, thus bringing new opportunities to make more intensive and dynamic use of spectrum. 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 ineffective regulation. 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, p. 75).

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. 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 have not been re-allocated or re-assigned. 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. The latter occurs usually because command-and-control regulation struggles to accommodate trading arrangements between spectrum users (Bykowsky, 2003), within a framework 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 al.*, 2004, p. 16), in particular by forbidding (or constraining) changes in spectrum use. Thus, valuable spectrum resources are left idle or put in the (tied) hands of licensees by regulatory fiat[1]. But there

[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 tradable, 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).

is also another relevant way in which regulation can contribute to (artificial) scarcity: regulation can inhibit the research and development of ways to reduce scarcity[2] and use the 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 public consultation) in order to reallocate the spectrum. This process is very often reliant upon consultations initiated by regulators on specific issues and there are also instances where the regulators decide to seek support from consultants and directly from regulatees, sometimes joined in consortia. Regulation of new and emerging technologies that have not yet appeared on the market is, however, a far more burdensome and trickier issue, because regulation runs the risk of picking a wrong option. It is crucial that regulatory decisions are made while new technologies are in their (early) development stage and before they enter the market for commercial deployment (Evci and Fino, 2001).

A number of new technologies 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

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

[3] These include: multi-band OFDM, UWB, MIMO/smart antennas, metamaterial antennas, software defined radios, data compression, turbo coding, interference 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.

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, smart antennas) are raising for spectrum management. 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 advanced 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, orthogonal frequency division multiplexing (OFDM) 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 spectrum sharing feature; ultra-wideband (UWB) enables the use of spectrum below the noise-floor; advanced antennas can increase coverage and capacity; and finally, *ad hoc* mesh networks(which work by relying data from node to node, rather than sending it back to a radio base station) 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 and have 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).

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; and 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

In Italy, since long time, use of the TV broadcasting spectrum has been characterized by features that make the Italian experience a peculiar one, indeed unique 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 claim part of the spectrum. This has lead to a situation that has been dubbed "far west" by some commentators, who point out that even national regulators struggle to get a clear picture of actual assignment of broadcasting frequencies[4].

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 led to a duopoly where two companies—Rai Radiotelevisione and Reti Televisive Italiane (Mediaset Group)—hold together over 10.000 frequencies 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[5]—something that had been made in other European states many years earlier—but this regulation was not implemented. Also, whereas other European regulators have pursued provision of broadcast content by independent 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 Ottavini, 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

[4]Agcom is trying to map the use of frequencies and build a database. Seemingly, there are some 20.000 Italian TV bases that are not registered according to the international regulations of Stockholm adopted in 1961.

[5]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).

technology only needs a fraction of input[6]. Therefore, the remaining 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 May 24, 2005 on "accelerating the transition from analogue to digital broadcasting" (EC, 2005b), set out the Community policy objectives for the switchover. It identified spectrum gains as one of the major advantages and 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 Scandinavia 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 quick in getting the transition started. This began with Law no. 66 of 2001, which set the switch-off date for December 2006, although at the end of December 2005 this deadline was delayed to 2008. Law no. 66 introduced broadcast infrastructure/frequency trading to allow tests of digital switch-over, thus 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). Also, trading is permitted only in some frequency bands.

Law no. 66 was intended to promote digital switch-over in the frequencies used for terrestrial TV, allowing the purchase of existing networks, or parts thereof, by firms interested in starting off tests in digital transmissions.

[6] "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, p. 4).

However, Law no. 66 restricted purchase of infrastructures/frequencies to those broadcasters who already had authorisation to provide the same kind of service, hence blocking entry for 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 approaches, possibly because of insufficient financial resources. According to national estimates reported by Agcom (2006a, para. 182), the average cost for switching analogue plants to digital transmission is likely to be in the range of €300K for those with great area coverage. National operators have estimated that €30-40M is needed for the deployment of a digital network (of 100-150 sites/frequencies) to broadcast digital terrestrial television in an area where 80% of the population is able to receive the programmes[7].

However, switch-off will not take place soon and Italy could still choose a different regulatory path. For instance, it would be useful to map spectrum usage in advance, in order to get information on spectrum usage before allowing secondary trades. Also, much of the spectrum in nearby frequency bands is held by the public sector, in particular by the Ministry of Defence. Spectrum refarming may be negotiated between the Ministry of Communications and the Ministry of Defence, to facilitate digital switch-over in a way similar to that adopted in the US by the FCC. 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 opening spectrum to new undertakings (Wik Consult, 2005)[8].

Law no. 249 of 1997 set at 20% the maximum amount of analogue net-

[7]ITMedia Consulting estimates the value of a frequency (i.e. a programme) that covers 95% of the population in the range of €240-270M, 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 billion (see *Corriere della Sera*, February 13, 2006).

[8]Some of the digital dividend will be used for public safety and particularly to facilitate inter-operability among public safety organisations. In some 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 other countries frequencies are not scarce and, therefore, no options are being considered (e.g. Canada). See Wik Consult (2005).

works and programmes that could be broadcast by the same undertaking using terrestrial frequencies. It also 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)[9].

5.2 WiMax systems: how command-and-control regulation can lag behind technological and market developments

WiMax offers a new wireless system standard with a wide range of possible operating frequencies. WiMax can transmit signals up to 50 Km and has greater throughput (hundreds of Mbps) compared to other wireless systems. Hence, it supports a number of applications, including fixed consumer and business broadband, backhaul (e.g. for WiFi hotspots) and mobile data services to handsets. Many deployment architectures are possible, but they are primarily based on the same architecture as 2G/3G systems.

This new system is struggling to enter 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 authorised WiMax tests in a number of Italian geographic locations[10], finally meeting manufacturers' repeated requests to be able to run tests of systems implementing the new standard. Actually, for a few years Agcom had been asking the Ministry of Communications to act in order that the relevant swathes of spectrum—mainly held by the Ministry of Defence for its own operations—were vacated. However, the Ministry of Defence still controls those frequencies being used to test WiMax and, meanwhile, the Ministry of Communications has delayed the deadline for

[9] It was also suggested to sell some of the spectrum controlled by the Ministry of Defence to mobile operators, using 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*, May 18, 2006).

[10] See http://wimax.fub.it/.

those tests. Agcom has recently contended that this situation has become unacceptable and has requested urgent action by the government (Agcom, 2006b, p. 9). At the end of December 2006, the Ministry of Communications and the Ministry of Defence finally agreed on a plan whereby 2x35 MHz will be available for WiMax in the 3.4-3.6 GHz band from June 2007. Also, the two ministries agreed that twice as many frequencies will be allocated to enable a nationwide spread of broadband services within five years.

Vacating the spectrum where WiMax can operate is costly, as the Ministry of Defence will have to move its fixed and mobile radar systems (as well as other telecommunications equipment) to different sites and frequencies[11]. The investments planned within the agreement will be financed by the State budget and perhaps also by revenues from commercialisation of WiMax. Whereas WiFi is developed within the unlicensed spectrum, WiMax service providers are looking for licensed spectrum to offer better service quality to their customers, while lower quality—and cheaper—services could be offered in unlicensed frequencies, probably those at 5.725-5.825 GHz. Moreover, the Italian regulator will have to allocate radio bandwidth in order to change use of the frequency 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. Flexibility in the use of spectrum is crucial.

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

The processes used to allocate frequencies for mobile services show how the 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: this could be improved if a more flexible approach, based on private property of frequencies, were 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 small amount of spectrum is in high demand because it enables better communi-

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

cations 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 had never used the 15 MHz of frequencies won in the auction. These 15 MHz of spectrum cost Ipse around *e* 3.3 billion. Ipse did not comply with its contractual obligations and has sought, through the courts, to reduce those obligations and thus 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), the regulator are still in the process of deciding how to re-assign frequencies (i.e. 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, particularly those of incumbent firms providing spectrum-based services, as well as those of regulators (whose role would be diminished by either a commons or a market regime). The literature, however, suggests that command-and-control regulation, as currently conceived, is defective and that a change in spectrum regulation is urgently needed[12].

There is considerable disagreement on the direction that spectrum reform should follow and the development of a viable spectrum management regime, as an alternative to command and control, is still at an early stage. In its 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

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

> 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, p. 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. In early stages of this controversy, there was clear opposition between free-market economists, who supported the introduction of wide-spread market mechanisms, and, usually, legal scholars and technology experts, who supported the commons formula (Faulhaber, 2002). Economists, like Ronald Coase, favoured placing all licences into the market, permitting both private and public licensees to buy, sell, trade, aggregate, and disaggregate spectrum rights, unfettered by government-imposed use restrictions. The lawyers and the engineers pointed to new wireless technologies and argued for a commons regime in spectrum with no property rights (Faulhaber, 2006, p. 539).

Recently, the conflict between these two views has waned and the idea has been advanced that both market mechanisms and commons regimes can prove useful in the design of a renewed approach to spectrum management. Considerable differences still remain regarding what should be the right mix of the two. Some believe that regulation should move towards more flexibility by reliance on market mechanisms, with forms of (private) commons regimes for parts of the spectrum (Ofcom, 2005a; Baumol and Robyn, 2006; Cave, 2006; Faulhaber, 2006). Others believe that spectrum management should be based on a commons approach (with open access), with individual and exclusive rights used only in specific instances (Benkler, 2002; Werbach, 2004).

Technological advances have been referred to by students in the latter group to promote 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 older technologies), the fast growth of WiFi applications (which provide wireless broadband access to data networks) and the promise of cognitive radio (with the capability to sense the surrounding environment and intelligently select the appropriate behaviour) have been used to argue against licensed spectrum and market mechanisms as the basic ingredients of a new approach to substitute for command-and-control regulation.

However, arguments against a spectrum commons regime can also be found. Spread spectrum technologies are often underlay techniques[13] operating across licensed bands and enabling operations by secondary users on a no-harm 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[14]. Also, the promise of cognitive radio is still a long way in the future and it is far from clear how self-coordination of complex independent devices will actually take place in a spectrum commons.

In the future, technological development may bring marketable devices that can intelligently organize communications among them and thus use the spectrum without causing too much reciprocal interference. However, this scenario is far from feasible with current hardware and software. Indeed, advocates of a commons regime approach (with open access to the whole spectrum) have not yet provided a viable solution to the problem of coordination which must be solved to avoid harmful interference. Reliance on development of social norms suggested by game theory is, according to Faulhaber (2005, p. 30), "romantic but fanciful". Contributions from game theory assume stable communities in which actions among players are part of the pattern of a repeated game[15]. In wireless communications, a multitude of users might transmit in the same frequencies and mobility is crucial; few homogeneous groups can be seen as players in a repeated game (e.g. amateur radio operators)—so cooperation is unlikely to occur. Moreover, Mahoney and Sanchirico (2003) suggest that, if the cooperative equilibria

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

[14]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). Advocates of a commons argue that spectrum should be open to anyone. However, one thing is an access regime, and another thing is a property regime.

[15]See, for example, Eatwell *et al.*, eds. (1989), Fudenberg and Tirole (1991) and Osborne (2004).

would require investments, it is likely that they will be unstable compared to non-cooperative equilibria[16].

Nevertheless, the concept of a commons regime is not to be rejected altogether. Actually, whereas a commons regime could not take over spectrum management using the command-and-control formula and perform better, parts of the spectrum may be used as a commons with a coordination mechanism provided by a central authority, such as a band manager, similar to, for example, WiFi. Indeed, the main drawbacks from the commons approach arise due to a confusion being made between a property regime (commons) and an access regime (Hazlett, 2006). It is open (unregulated) access to valuable (scarce) spectrum that would lead to what has been called—paraphrasing Garrett Hardin's tragedy of the commons—a spectrum tragedy (Hazlett, 2005). In that situation, too many users seeking access to the same resource would eventually end up causing harmful interference and blocking transmissions altogether. Open access would bring about exactly what the introduction of spectrum regulation intended to avoid and control for: chaos in the ether (Coase, 1959; Hazlett, 2001). Ultimately, open access implies that spectrum belongs to nobody and is also beyond end-state regulation:

> "open 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, pp. 85-6).

As argued above, 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. A commons regime has an owner (or is owned by a group); therefore open access and chaos can be avoided, since it will be

[16] See Faulhaber (2005, p. 30) for details on this argument based on contributions from game theory.

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 allocated by market forces: the owner(s)—both private and public—can buy, sell, trade, aggregate and disaggregate their spectrum.

And whereas Kwerel and Williams (2002), in their plea for the use of market mechanisms, suggested a big-bang auction of all spectrum, advocates of an open access regime have not suggested how to abandon current command-and-control regulation and move to their envisioned scenario. Thereby, although there are ways to move forward in regulating spectrum more efficiently within the property rights paradigm, no such pragmatic guidance has emerged with regard to other paradigms.

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 is implemented (preferably, as maintained above, a property rights regime), inefficiencies in spectrum management are likely to persist.

7 Towards a new spectrum strategy

In the past, relatively slow technological change and relatively abundant spectrum availability combined to mitigate any command-and-control regulation inefficiencies. Over the years, regulators have tried to cope with (increasing) technological change and (booming) demand in wireless communications by adjusting, piecemeal, frequency allocation[17]. 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, 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.

[17] In Europe, the Radio Spectrum Policy Group (RSPG), which advises the European Commission, is pursuing a more unified regulatory regime. In particular, the RSPG is elaborating on the concept of Wireless Access Policy (formerly Platforms) for Electronic Communications Services (WAPECS). Notably, WAPECS aims to introduce more flexibility in the use of radio frequency spectrum, taking into account that, presently, different platforms and technologies may provide mobile, portable and fixed access for a wide range of electronic communications services, including converging applications (RSPG, 2005).

Auctions were first advocated by Coase in 1959 and were immediately rebuffed by the FCC as a "big joke", but they were eventually espoused by regulators fifteen years ago (Hazlett, 2001); so command-and-control regulation has used market mechanisms for primary assignment of radio frequencies.

Some regulators have also introduced frequency trading, e.g. the UK and Australia, hence allowing the market to move spectrum from one user to another. However, spectrum trading, without liberalization of frequency use, does not solve the problem of regulatory misallocation of frequencies (Valletti, 2001; Hazlett, 2003; Analysys *et al.*, 2004). Moreover, in those countries where licences can be traded, only a limited number of trades has taken place, often among firms under the same parent company (Wik Consult, 2005)[18].

More recently, the promises (as well as the challenges) of new and emerging technologies, which enable novel and more intensive ways to share spectrum among users, have suggested to allow more flexible arrangements in spectrum management. In the US, "easements" have been suggested (Faulhaber and Farber, 2002) to enable secondary users to transmit in the frequencies of a licensed user, provided that the latter do not suffer any harmful interference. Easements might be useful for applications based on ultra-wideband technology (which transmits 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 spectrum easements might be easily introduced (either by simply modifying existing licences or by re-issuing them), they might also accommodate the open access advocates' proposal for spectrum resources (Faulhaber, 2005): this novel arrangement would be very much crafted in the existing framework of command-and-control, but it is unclear how "a governmental rule without price and profit incentives will be able to match the performance of a market regime" (Baumol and Robyn, 2006, p. 62).

To develop a full-fledged (secondary) market, both proposals would need regulation to properly define and allocate spectrum usage rights. Regulators

[18] A number of reasons may be given for the generally low level of trading experienced internationally: for instance, scarce public information about spectrum use (in particular, price information), lack of consistency of licence terms and conditions, availability of unused spectrum, large programmes of primary awards, uncertainties due to phased liberalisation of spectrum use and likely modifications of spectrum usage rights by regulatory fiat.

have two main options. The first option would be to re-issue all existing licences, by transforming them into spectrum property rights designed around 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 (Ercole, 2005). 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, this would present redistribution issues (Kwerel and Williams, 2002). Moreover, 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 would have to design an appropriate bundle of rights (Cave and Webb, 2003b).

A few regulators—particularly in Australia and the UK—have taken significant steps in this direction. Broadly, in order to manage interference with a minimum amount of regulation[19], the new licences would set the maximum transmission 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 types of interferences, i.e. geographical interference, out-of-band interference and in-band interference (Ofcom, 2006). Thus, instead of specifying technical restrictions on spectrum use to protect neighbouring users against harmful interference indirectly, such alternative approach aims to directly specify the emissions that a licence holder may transmit in neighbouring bands or locations. According to Ofcom, "this could bring two key advantages: 1) licensees would have greater flexibility since their licences would not restrict the technology or application; 2) neighbouring licence holders would have more clarity over the levels of emissions from neighbours they can expect" (Ofcom, 2006, pp. 3-4). In Australia, spectrum property rights have already been introduced success-

[19]The design of more flexible (and tradable) spectrum usage rights involves also other issues: in particular, national regulators seem reluctant to introduce perpetual usage rights and insist that they should decide the appropriate duration of such rights. In the UK, the recommendation to introduce perpetuity of rights, made in a recent official report (Cave, 2002), has not been followed, and Ofcom can withdraw licences after a certain number of years has elapsed.

fully (PC, 2002) and few issues of interference among users have arisen (Wik Consult, 2005). However, some users have contended that regulators tend to grant spectrum rights to particular applications, thereby failing to meet service neutrality: those users advocate further flexibility to change the current arrangement. The US has recently adopted a technology-neutral approach in the aftermath of the Spectrum policy task force report, but there are often problems with radio interference when new technologies are introduced.

8 Administrative incentive pricing

The design and implementation of a new spectrum management regime is likely to take considerable time, irrespective of whether reviews of spectrum strategy favour a commons or a full-fledged market regime (EC, 2006). However, there are ways to promote efficient spectrum use by relying on a hybrid solution, i.e. administrative incentive pricing (AIP), which adopts a market approach and may be quickly introduced. AIP is an incentive based pricing technique built on the principle that any use of spectrum imposes an opportunity cost on society—the value foregone of alternative use. The aim of AIP is to ensure that spectrum holders fully recognize this when making decisions on spectrum holdings or acquisitions.

8.1 Spectrum charges and administrative incentive pricing

AIP is based upon identifying the economic value of radio spectrum. 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 to 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 would take account of changing scarcities (Cave *et al.*, 2007).

In a study for Ofcom, Indepen *et al.* (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 will there be 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 practical or feasible to collect AIP fees given possible constraints due to avoidance or illegal use?

- are there any policies or political factors that impede the use of AIP?

In cases where AIP is not appropriate—because the marginal opportunity cost of spectrum is zero—license fees should be set only to reflect the spectrum management and enforcement costs caused by each service. Therefore, regulators have adopted different financing schemes, classified into four 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 some of the following features are generally considered by regulators (Yu *et al.*, 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 license 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 license 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

In the United Kingdom, a study conducted for the Radiocommunications Agency by Nera and Smith System Engineering (Smith-Nera, 1996) proposed a methodology to introduce administrative prices that reflect the marginal opportunity cost imposed on society by the use of spectrum resources. 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 or rural). However, most of the cost was biased towards the areas where spectrum was scarce (Indepen *et al.*, 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 could 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 does not provide the highest value. It would then be for the regulator to decide how to set a price to encourage efficient allocation[20].

However, there may be instances where a piece of spectrum used for service A cannot be changed to a higher value service B (even if service B caused no more interference than service A) for reasons that are beyond a spectrum user's ability to change (for example, international regulation, or the lack of availability of equipment in suitable volumes or prices). Thus it would not make sense to charge users, in a given frequency band, at an AIP level for a higher value service.

A further refinement is to ask the question of what happens if the amount of spectrum can not be altered gradually, whilst keeping the same output. For example in analogue TV broadcasting in Europe, an 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 to model costs and consumer demand. This then is a full blown modeling exercise to calculate the net present value and this would reveal likely spectrum bid value at auction.

[20]The aforementioned work by Indepen *et al.* (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.

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 MHz were to be taken from a Public Access Mobile Radio (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 (i.e. €75K).

More crucially, the value that emerges from any AIP calculation is highly dependent on what amounts of spectrum are chosen for the start and end points of the analysis. This is because the value of spectrum for a network operator will follow a diminishing marginal value law: for example, a GSM operator with 2x5 MHz of spectrum is likely to value an extra 2x5 MHz very highly, compared to an operator with 2x20 MHz (who is likely to value such an amount of extra spectrum far less)[21]. AIP is also highly sensitive to the start and end conditions chosen, as well as what services are assumed to be allowed in a given frequency band. Thus, without a detailed understanding of these issues, it might be that the values derived from an AIP calculation could vary wildly.

8.3 AIP and the impact of spectrum on costs

The following table gives an example of the calculation of AIP, based on the Smith-Nera method. The calculation is highly 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 is 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 reduction in the costs associated with these 84 sites is the upside of the AIP calculation. The downside is the extra costs of more radio transceivers.

The table shows, on the one hand, the savings from having 84 fewer sites (which is possible from having an extra 2x3 MHz) and, on the other hand, the additional costs of buying more transceivers. There will be a cost associated with installing these extra transceivers, but it is assumed here the cost is

[21] At some point, an operator will find that the marginal value of extra spectrum is zero. However, AIP should not be used if it helps an operator with significant market power increase its market power.

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:

Savings from 84 fewer sites	Capital	€6,720,000
	Annual	€1,512,000
Costs of more transceivers to use extra 2x3 MHz	Capital	€2,520,000
	Annual	€252,000
Difference	Capital	€4,200,000
	Annual	€1,260,000

The capital figure is annualized over 10 years and this gives 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 2x3 MHz of spectrum and, with fifteen 2x200 kHz GSM channels, this equates to a fee of €128,246 each.

8.4 Fit for purpose

AIP has already been applied in the United Kingdom since 1998 (and has generally become more sophisticated). A few countries in the process of reviewing overall spectrum pricing policy are considering incentive based spectrum pricing to encourage efficient spectrum use (e.g. Denmark, Canada, India, Singapore and Japan). The level of complexity and detail, that is required in any AIP scheme, depends on the policy objectives and on the local market situation. For instance, Australia and New Zealand have allowed for a system of spectrum pricing that embodies in part the principle of opportunity costs, 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.

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 suddenly: the traditional approach to spectrum management cannot abruptly be replaced by either a commons regime or a property rights regime, because there are several 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 from practices aimed at coping with contingencies and withdrawal 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 and artificial scarcity of spectrum resources.

While the discussion about the introduction and development 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 (for allocation or 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 gains, particularly by enabling efficient re-allocation of frequencies.

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