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Spectrum management reform: Rethinking practices

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ABSTRACT

Unparalleled growth in wireless communications has increased the pressure for more spectrum to support more users, more uses and more capacity. To alleviate that pressure, major regulatory changes were introduced in several countries in two key areas of spectrum management, namely spectrum assignment and allocation. This paper analyzes those changes and discusses strategies and tactics for deregulating the use of radio spectrum. Spectrum management reforms are considered within the theoretical framework of transition economics, which is concerned with optimal reform speed and sequencing. The paper shows how Anglo-Saxon and European countries have been implementing gradual reforms. Meanwhile, Central American reformers have chosen a fast transition from command-and-control regulation to market mechanisms. Transition economics is used to evaluate the advantages and drawbacks of different spectrum reform strategies.

1. Introduction

Over the past two decades, unparalleled growth in wireless communications has increased the pressure for more spectrum to support more users, more uses and more capacity. Therefore, some regulators have introduced changes to their traditional command-and-control approaches to spectrum management, as administrative methods have created artificial gaps between spectrum demand and its supply (Faulhaber, 2005; Cave, Doyle, & Webb, 2007; Hazlett, 2008a).

Studies on several issues of spectrum management modernization have been abundant, and a wide range of spectrum management regimes have been proposed to suit innovative wireless communications systems (Pogorel, 2007; Freyens, 2009). However, there seems to have been little analysis of strategies and tactics to liberalize the use of radio spectrum, based on theoretical frameworks that can help us to understand the merits and pitfalls of various deregulation processes, featuring different speeds and reform sequences.

This paper builds on the view that the modernizing of spectrum management has similarities with the abandonment of Gosplan regulation, and it elaborates on the assertion that "[r]eforming spectrum policy is like reforming planned economies" (Kwerel & Williams, 2002, p. 40). To achieve these goals, theories developed within analyses of transition economics, from planned economies to more market-based economies (Roland, 2000), are applied to the case of spectrum policy reforms. The aims are twofold: from a positive perspective, to analyze the key spectrum policy reforms introduced in a few liberalizing countries and from a normative perspective, to contribute to the study of how transitions from command-and-control methods toward market-based methods, for spectrum assignment and allocation, might best be managed to maximize the expected outcomes.

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This work shows that research on transition economics offers several insights into the study of implementation strategies for spectrum management reforms. It also offers some spectrum policy guidance by suggesting: first, instances in which fast reforms are expected to be better than gradual ones; and second, for gradual reforms, which spectrum reform packages should be adopted in early stages of liberalization and which should be adopted in later stages.

The remainder of this paper is organized as follows. Section 2 reviews studies that deal closely with the problem of identifying trajectories of spectrum policy reform, and it introduces a few fundamental propositions from transition economics, providing some background for the analyses of spectrum policies in the subsequent sections. Specifically, Section 3 considers deregulation of spectrum allocation and assignment as the two key reform packages in a few liberalizing countries, to highlight the speed and sequencing of modernization of their spectrum management frameworks. Elaborating on several transition economics propositions, Section 4 presents a discussion of the advantages and drawbacks of different spectrum deregulation strategies; spectral encumbrance status is given particular consideration in the discussion of how transitions from command-and-control regulation toward market mechanisms might best be managed. Section 5 concludes the study.

2. Transition from command-and-control regulation to market-based mechanisms

The introduction of market mechanisms in various areas of spectrum management has been the focus of an extensive literature. A number of studies have provided estimates of the expected social benefits from spectrum liberalization, and they have shown that liberalization of both spectrum use and trading would accrue much greater benefits than trading only.[1]

Few authors, however, have analyzed transition roadmaps to move from a command-and-control regime to a more flexible spectrum management regime. Kwerel and Williams (2002) proposed reallocating restricted spectrum to flexible use and conducting large-scale two-sided auctions of spectrum voluntarily offered by incumbents, together with any unassigned spectrum held by the FCC. Thus, a rapid and efficient restructuring of spectrum rights and use could be facilitated by ensuring that most spectrum was up for sale at the same time.[2] Wellenius and Neto (2007), in a study on spectrum management reform in developing countries, outlined three of the many options that could be considered for spectrum policy: (a) do nothing; (b) move as quickly as possible; and (c) improve piecemeal at the margins. They argued that, whenever a country's conditions permit, it is preferable to move quickly and that radical solutions might be easiest to implement when spectrum management is least developed.[3] Finally, in a study on European spectrum policy Bohlin, Blackman, Forge, and Renda (2007) used SWOT analyses to discuss three major options for the implementation of proposed spectrum reforms regarding some key areas of spectrum management, such as technology and service neutrality, harmonization and unlicensed use: (a) a big bang for all of the European Union; (b) progressive implementation of reforms, with planned transitions across Europe in the major areas considered;[4] and (c) staged implementation, either by geographic blocks or by individual Member States in a series of phases.

In the transition economics literature, the defense of a big-bang strategy has often been based on the complementary nature of reform packages (that is, smaller parts, which represent sub-divisions of a major reform). However, further research has shown that complementarity of reform packages can, on the contrary, provide an advantage to gradualism, because gradualism enables the sequencing of reforms to maximize expected welfare under uncertainty (Roland, 2000). Indeed, spectrum management reform involves a considerable amount of uncertainty, because relevant information will often become available only when implementing deregulation (such as information about marketable wireless technologies, levels of actual harmful interference, services in high demand and anti-competitive behavior in spectrum markets).

Transition theories propose that, under uncertainty, informativeness — which is used "in the sense that learning about one reform tells whether to try another reform or not" (Dewatripont & Roland, 1995, p. 1211) — is the primary necessary condition for gradualism to dominate the big-bang strategy. Policy makers should choose gradualism when this course of action can provide crucial information about future states of the world, signaling whether it is better to continue the reform process or to return to the status quo. In the case of gradual reforms, informativeness has immediate implications for sequencing: whenever possible, reform packages should be sequenced to provide information for decisions regarding the next step of the reform process (Dewatripont & Roland, 1995). This rule goes in the direction of evolutionary thinking: "because of the assumption of aggregate uncertainty, one has little to say about the end point of transition, and one will emphasize more the process of learning about possible outcomes through the transition strategy chosen" (Roland, 2000, p. 41). Under an evolutionary approach, information can be accumulated through the reform process; each step is small, and errors are not too costly. In contrast, the planner of big-bang reforms must know much (McMillan & Naughton, 1992;

[1] These benefits are largely due to greater innovation and competition from liberalization (cf., e.g., Analysys, Dotecon, Hogan, & Hartson, 2004, who used a methodology that was followed in later studies on other liberalizing countries; London Economics, 2008). See also Forge, Horvitz, and Blackman (2012) on shared spectrum access.

[2] According to their proposal, 438 MHz of spectrum in the 300–3000 MHz bandwidth could be restructured in as little as 2 years, significantly reducing spectrum shortages for high-demand uses.

[3] They contended that "[n]ew solutions are likely to be tried first in situations on which there is experience elsewhere and the risks are low, or where risks are higher but payoff in terms of economic or social benefits is large" (Wellenius & Neto, 2007, p. 55).

[4] This is the authors' preferred option, as it might be the most pragmatic.

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Murrell, 1992). Moreover, gradualism makes reforms easier to start, because it provides the additional option of early reversal at a lower cost, compared to a big-bang strategy.

To take greater advantage of transition economics, in the following analysis of the speed and sequencing of spectrum management reforms, two relevant areas of the deregulation of spectrum use are assumed: (a) *Deregulation of assignment* (DASS), that is, changes in the mechanisms that authorize users to access spectrum (notably by introducing auctions and allowing secondary trading and transfers); and (b) *Deregulation of allocation* (DALL), that is, changes in the framework governing the choice of wireless services, as well as their enabling technologies, by delegation to (licensed) spectrum users of decisions regarding how to use their spectrum efficiently (Cave et al., 2007).

In the remainder of this paper, DASS and DALL will represent two major reform packages of spectrum policy. Hence, applying transition economics, these two proposed reform packages will constitute the building blocks for positive and normative analyses of spectrum management reform strategies in liberalizing countries.

3. International experiences of spectrum management reform

Several countries have been at the forefront of spectrum reforms and have provided evidence regarding the major liberalization strategies aimed at introducing market-based mechanisms for spectrum management. The countries selected for analyses of spectrum reform packages are the European Union, the Anglo-Saxon countries (the United Kingdom, the United States, Australia and New Zealand), Guatemala and El Salvador. To highlight the speed and sequencing of these countries' reforms, fundamental DASS and DALL developments are briefly reviewed below (reforms are then discussed in Section 4).[5]

3.1. The European union

The flexibility of spectrum management to enhance efficiency, especially in frequency bands used for commercial services, has been an important theme in European policy for many years. Spectrum management is still largely a Member State competency; however, it should comply with EU law, policy milestones for which were set in 2002.[6]

3.1.1. DASS

European countries are using competitive bidding to assign spectrum licenses for frequency bands in high demand. The most relevant experience has been the European UMTS/ IMT-2000 license assignment in 2000–2001. In 2002, the *Framework Directive* permitted member states to allow for the transfer of the rights to use radio frequencies between undertakings. In November 2004, the Radio Spectrum Policy Group (RSPG) adopted a cautious stance on trading (RSPG, 2004): they favored a phased approach, leaving the decision to individual countries regarding introduction (or not) and timing. The RSPG was also skeptical about the application of trading in bands catering to some public interest services. However, in 2009, the RSPG published an opinion stating that trading offers public bodies the flexibility to enter into leasing arrangements (RSPG, 2009).

3.1.2. DALL

In 2004, the European Commission (EC) invited the RSPG to prepare an opinion on WAPECS (Wireless Access Platforms, later changed to Policies for Electronic Communications Services). The RSPG defined WAPECS as "a framework for the provision of electronic communications services within a set of frequency bands […] in which a range of electronic communications networks and electronic communications services may be offered on a technology and service neutral basis, provided that certain technical requirements to avoid interference are met" (RSPG, 2005, pp. 2–3). In 2006, the EC proposed that "based on common EU rules, greater flexibility in spectrum management could be introduced by strengthening the use of general authorizations whenever possible. When not possible, owners of spectrum usage rights should not be unduly constrained but, subject to certain safeguards, have the freedom to provide any type of electronic communications service ('service neutrality') using any technology or standard under common conditions ('technological neutrality')".[7] Furthermore, in 2006, the European Parliament urged the Commission to facilitate the coexistence of different types of licensing models.[8] Then, in 2010, the RSPG, in its opinion on the first radio spectrum policy program, also stated that management of spectrum for military and civil (commercial and non-commercial) services should be reviewed to take account of best practices (RSPG, 2010).

[5] The aim here is to provide essential information about major steps in the implementation of spectrum policy reforms in the two areas identified for analysis (DASS and DALL). Much more information on several piecemeal issues is available in a number of reports (e.g., McLean Foster & Co., 2007) and by browsing regulators' documents. Some readers might prefer to move on to the discussion of spectrum policies.

[6] See http://ec.europa.eu/information_society/policy/ecomm/radio_spectrum/documents/legislation/index_en.htm#dir2002. This legislation was amended in 2009.

[7] See http://www.europarl.europa.eu/oeil/popups/summary.do?id=944476&t=d. A noteworthy example is the approval of the revised GSM Directive: the updated Directive allows the 900 MHz frequency band to be used to provide faster, pan-European services, such as mobile Internet, while ensuring the continuation of GSM services.

[8] European Parliament resolution *Towards a European policy on the radio spectrum*, (2006/2212(INI)), adopted in 2007.

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3.2. The United Kingdom

The UK has been at the forefront of spectrum policy reform among European countries (Cave, 2002). In its *Spectrum framework review* (SFR) of 2004, Ofcom announced a new deregulatory approach (Ofcom, 2004).

3.2.1. DASS

SFR indicated that Ofcom's preferred method of spectrum assignment to operators — particularly when demand is likely to exceed supply — is by way of auction. Spectrum trading was introduced at the end of 2004. Since then, trading has been progressively extended to a broad range of licenses. The holders of certain wireless telegraphy licenses are allowed to transfer all or part of their rights and obligations to other parties.[9] However, trading volumes have been low, especially at the beginning.

3.2.2. DALL

The liberalization process was launched in 2005 in three license sectors: business radio; fixed wireless access; and fixed links. In 2006, in experimenting with property rights licensing, Ofcom introduced spectrum usage rights (SURs), which restrict the interference a license holder is allowed to cause, rather than restricting transmitted power (Ofcom, 2006; Webb, 2009). Although very few licenses were issued, the SURs represent a rare example of a service-neutral regime in Europe. Ofcom also introduced two different ways to liberalize specific groups of licenses: (a) by changing existing individual licenses, for which license holders submit an application for a change to the usage conditions; and (b) by generically changing the license conditions. This second approach was aimed at making the license conditions as flexible as possible.

3.3. The United States

Liberalized spectrum management primarily relates to non-government spectrum (government spectrum, especially for military use, continues to be under command-and-control methods).

3.3.1. DASS

In 1993, taking into account budget requirements and the defects of lotteries, the FCC was provided with the statutory authority to conduct spectrum auctions, which have been used since 1994. With regard to secondary trading, the 2002 *Spectrum Policy Task Force report* expressed its support for a clear definition of tradable property-like rights for spectrum (FCC, 2002, esp. pp. 55–58). Two alternative models of spectrum reuse were promoted: (a) a secondary markets model, which enables the licensee to determine what rights it is willing to sub-license, if any, and to whom; and (b) an easements[10] or underlay model, which entitles the regulator to determine what rights, if any, must be provided to third parties.[11] Then, in 2003, procedures for spectrum leasing were substantially liberalized.[12] The FCC provided two modes of liberalized arrangements. The first mode is spectrum manager licensing, in which the licensee retains both de jure control (i.e., legal control) and effective de facto control (i.e., working control) over the leased spectrum. The second mode is the de facto transfer mode, in which the licensee retains de jure control but transfers de facto control to the lessee; in this case, prior FCC approval is still required. In 2004, the FCC further liberalized the process; most notably, the FCC attempted to clear the way for forms of opportunistic use of spectrum.[13]

3.3.2. DALL

By and large, US spectrum access regulations have focused on power limits to constrain spectrum use and harmful interference among users. Thus, with regard to technology and service neutrality, the US approach has allowed for flexibility in the rules for spectrum use, especially after the adoption in 1999 of new spectrum management principles to encourage technological innovation. However, the FCC power limits could greatly (or even excessively) restrict the range of technologies/services permitted in a radio frequency band (Hazlett, 2008a; Kwerel & Williams, 2010).

3.4. Australia

Australia began a series of major policy reforms in the early 1990s (BTCE, 1990).

[9] See http://www.ofcom.org.uk/radiocomms/ifi/trading/tradingguide/tradingguide.pdf on the different types of transfers allowed.

[10] Under US law, an easement is a limited right to use property belonging to another, especially to gain access.

[11] For instance, UWB devices are permitted to operate in licensed spectrum without first obtaining the permission of the licensee.

[12] See http://wireless.fcc.gov/licensing/index.htm?job=secondary_markets, *First report and order and further notice of proposed rulemaking (FCC 03–113).*

[13] See http://wireless.fcc.gov/licensing/index.htm?job=secondary_markets, *Second report and order, order on reconsideration, and second further notice (FCC 04–167).*

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3.4.1. DASS

In 1994, Australia held an auction for the first time to assign MDS spectrum (2.3 GHz). A number of broadcasting and open narrowcasting[14] licenses were auctioned between 1996 and 2005, although auction activity has slowed drastically since 2001 (with the collapse of the dotcom boom). Trading of spectrum licenses — a new market-oriented form of licensing — was a fundamental element of the Radiocommunications Act 1992;[15] however, the first spectrum licenses were not issued until 1997, and apparatus licenses — the traditional administrative type of licenses — became tradable in 1995. Spectrum license holders are able to sell, lease, repackage and change the use of their standard trading units (STUs), which cover a predetermined geographic area and frequency band.[16] Notwithstanding the introduction of STUs, the rate of trading has been quite slow (Productivity Commission, 2002; ACMA, 2008).

3.4.2. DALL

Apparatus licenses remain very service- and technology-specific. Spectrum licensing has created additional flexibility, as no service or technology constraints are specified.[17] However, technical frameworks for spectrum licenses (SLs) are designed with an intended use in mind, and once a license has been issued, its core conditions can only be changed by the ACMA. In the 2.3 GHz band, a large number of SLs were expected to be used for WiMax, but they were eventually left idle by their owner (Austar), particularly in non-metropolitan areas (Freyens & Yerokhin, 2011). A similar problem was encountered in two 4 MHz wide spectrum spaces around 500 MHz; after public consultation, the ACMA determined that those licensed spaces were not favoring the types of services which are most likely to use this frequency band. Therefore they reverted to apparatus licenses in 2012.

3.5. New Zealand

New Zealand has gone further than most countries in treating spectrum as a commodity, but continues to manage most frequency bands administratively (Jackson, 2011). The *Radiocommunications Act 1989* established a new spectrum licensing regime: (a) the management rights regime (MRR) provides flexible management in approximately 30%of spectrum and is applicable to spectrum used primarily for commercial purposes; (b) the radio license regime (RLR) applies to spectrum used for services of public interest, or where there is no shortage of spectrum supply; finally, (c) general user licenses (GULs), managed under the MRR or the RLR, are designed for low powered devices such as garage door opening systems and WiFi (MED, 2005).[18]

3.5.1. DASS

The MRR treats spectrum rights as tradable property and encompasses two tiers of spectrum rights: first, management rights (MRs), which give holders exclusive rights to a frequency band for up to 20 years; second, spectrum licenses, which are assigned within MRs by a right holder. The Radiocommunications Act 1989 allowed spectrum transfers from one manager to another; then the Radiocommunications Amendment Act 2000 gave government the power to sell or auction MRs.[19] The first (sealed-bid, second price) tender took place in 1989. The level of secondary trading was low at the beginning, and mainly confined to FM and AM radio broadcasting licenses; moreover, trades had not involved a change in use (MED, 2005).

3.5.2. DALL

The MRR allows to allocate spectrum in its most flexible and technology-neutral form, according to the type of service proposed by right holders and the criteria against which access is assigned (MED, 2005). As a result of a recent inquiry, no major changes were proposed to the current spectrum management framework. Congestion problems are dealt with on a case-by-case basis (MED, 2009).

3.6. Central American reformers

Guatemala adopted a simple form of spectrum market, which, in the case of non-public sector spectrum, gave private parties exclusive control over bandwidth usage (Ibarguen, 2003; Hazlett, Ibarguen, & Leighton, 2007). The *Ley general de*

[14] Open narrowcasting services are broadcasting services the reception of which is subject to limitations; see http://www.acma.gov.au/web/standard/pc=PC_90044.

[15] The Act provided for a new comprehensive system of licensing. A *spectrum licence* authorizes the operation of (non-specified) devices within a defined spectrum space and licence conditions; it is fully tradable, can be divided and aggregated and is issued for periods of up to 15 years. An *apparatus license* generally authorizes the operation of a transmitter or receiver at a particular location. A *class license* provides open access to spectrum on a shared basis (use of equipment in class-licensed bands must comply with license conditions).

[16] See http://www.acma.gov.au/scripts/nc.dll?web/standard/1001/pc=PC_300171. Note that the *Radiocommunications Act 1992* has safeguards for change of use (in particular, the regulator can change license conditions, with or without agreement from the license holder).

[17] Examples include the introduction of the wireless broadband service (in part of the spectrum licensed band used elsewhere for 3 G mobile telephony) and the introduction of a land mobile network for the Western Australia police force, using the spectrum licensed 500 MHz band.

[18] This licensing regime shares similarities to that in Australia.

[19] Government has chosen to retain some MRs (and to issue spectrum licenses), typically for broadcasting uses.

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telecomunicaciones of 1996 introduced the so-called *titulos de usofructos de frecuencias* (TUFs, i.e., a system of usufruct titles to spectrum).[20] TUFs can be leased, sold, subdivided or aggregated at will, and they last for 15 years (renewable on request). Individuals can apply for TUFs to any unused spectrum, and in cases of competing applications, the TUFs are auctioned. Following the enactment of the law, approximately 3000 TUFs were auctioned between 1997 and 1999. The Guatemalan independent regulatory body is responsible for the registry of TUFs and was conceived of as an administrator to enforce specified rules. Interference problems are solved first by private negotiation and then by arbitration, if necessary (Ibarguen, 2003).

In 1997, El Salvador adopted a reform similar to that introduced in Guatemala. Any person or firm could request the titles to frequency bands not assigned to other users. Assignments became usufruct titles, not subject to being reclaimed by the government; however, annual spectrum fees must be paid in El Salvador (Hazlett et al., 2007).[21]

4. Discussion of spectrum policies in transition

In the liberalizing countries surveyed, strategies for spectrum management reform have differed substantially. Central American reformers are the only ones who have chosen a somewhat big-bang approach, whereas most countries have been moving gradually from command-and-control regulation to more decentralized decisions of spectrum management (Table 1).

Gradual reforms usually start from DASS in a few frequency bands allocated to commercial services: spectrum auctions are held in cases of excess demand, while spectrum secondary trading and transfers are considered for an increasing number of bands. Change of use (i.e., DALL) is introduced later, and it appears to be subject to close regulatory scrutiny (for instance, in the US, in the UK and in Australia). By and large, expansion toward more private property-like rights to use spectrum has lagged.

Implementation of gradual strategies has benefitted from learning from experience regarding the effectiveness of various policy actions. This learning has influenced the reform process and suggested policy changes as reforms were being implemented. The country survey shows that regulators have consulted with stakeholders, to ease collection of information on the techno-economic use of spectrum and to make information publicly available whenever possible. In general, deregulation has been undertaken with regard to various frequency bands in an incremental manner (e.g., WAPECS in Europe). Different types of licensing regimes have coexisted and less rigid procedures have been used to change spectrum assignment or allocation (e.g., for spectrum transfers). In addition, reforms undertaken in other countries could be used as further experiential learning (cf. Dewatripont & Roland, 1995, p. 1212; Pitlik, 2007); however, policy actions cannot be imported from one country and applied elsewhere in a straightforward manner (cf. Murrell, 1995).

4.1. Uncertainty, informativeness and evolutionary reforms

The role of information is central to evolutionary theories, which emphasize the benefits of gradual approaches where there is uncertainty. Hence, transitions should proceed incrementally where information that could steer reform processes can be collected along the way. For instance, in some cases, the Australian regulators have been more conservative than originally envisaged (as in the design of neutrality parameters for licenses awarded in some recent auctions). To provide another example, the UK regulator apparently shelved its 2004 plans regarding implementation of SURs, although growing interest in spectrum sharing, in some frequency bands, is regenerating attention in SURs (Cave & Webb, 2012).

Some countries' decisions to adopt fees based on opportunity costs can be similarly considered in the evolutionary perspective.[22] Incentive fees can be useful in gradual reforms as a proxy for spectrum markets and as a means to gather information to help develop a reform program. In fact, opportunity cost schemes have the potential to reveal, for instance, situations where services occupy spectrum inefficiently (as happened with some public spectrum holdings in the UK and elsewhere).

4.2. Big-bang versus gradual reforms

Transition economics literature has provided some insights into the striking difference between the rapid liberalization implemented by Central American reformers and the gradual reforms chosen by others. Theoretical research has suggested that big-bang reforms can be optimal in circumstances in which there is a sufficient combination of: (a) a positive and large outcome expected from a big-bang strategy; (b) no learning from partial reforms or no option value of early reversal of a

[20] A physical TUF is a paper certificate listing the frequency band, hours of operation, maximum transmitted power, maximum power emitted at the border, geographic territory and duration of rights.

[21] In some countries, spectrum fees based on opportunity cost have been used. This practice is discussed below.

[22] Use of AIP (i.e., administrative incentive pricing) for public sector spectrum holdings, which are not priced on the market, introduces payments that move away from mere cost recovery (Cave et al., 2007, esp. Ch. 12). In the UK, the spectrum used by the Ministry of Defense constitutes a conspicuous example of AIP. Australia arguably had a system of AIP, although on an ad hoc basis, at least since the 1980s. Other countries have introduced, or considered, opportunity cost pricing; for instance, Canada has its *Spectrum efficiency incentive pricing*.

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Table 1
Major liberalization measures and timing in the countries surveyed.

	Major liberalization measures and timing		
	Deregulation of assignment (DASS)		Deregulation of allocation (DALL)
	Spectrum auctions	Spectrum secondary trading	
Europe	2000–2001, 3 G spectrum auctions	2002, *Framework Directive*	2005, Communication on a market-based approach 2006, review of EU regulatory framework
UK	2000, first auction	2004, *Spectrum framework review*	2006, *Spectrum usage rights*
USA	1994, first auction	2003, *First report and order* (*FCC 03–113*) 2004, *Second report and order* (*FCC 04–167*)	1999, statement on principles to encourage the development of new telecommunications technologies 2002, Spectrum Policy Task Force
Australia	1994, first auction	1995, trading of apparatus licenses 1997, trading of spectrum licenses	1992, *Radiocomm. Act* 1997, spectrum licenses
New Zealand	1989, first auction	1989, *Radiocomm. Act*	1989, management rights regime
Central America	1996, *Ley general de telecomunicaciones* (Guatemala) 1997, *Ley de telecomunicaciones* (El Salvador)		

negative outcome;[23] or (c) too costly partial reforms, notably because of delays in the implementation of welfare-increasing policies (Roland, 2000). It can be argued that this was the case in Central America (cf. Ibarguen, 2003; Hazlett et al., 2007), where a gradual spectrum reform would not have been informative, that is, able to provide signals to maximize expected payoffs by appropriate sequencing of reform packages.

In Guatemala and El Salvador, spectrum was not as encumbered as in other countries (cf. also Cave et al., 2007, Ch. 16; Wellenius & Neto, 2007). European and Anglo-Saxon countries make extensive use of spectrum; therefore, spectrum policy changes require much technical information and careful scrutiny to address a variety of technological, economic and legal issues, such as harmful interference, anti-competitive behavior, windfall gains and losses. For instance Kwerel and Williams (2002) suggested that consumers would benefit from their proposals of spectrum liberalization, while business and the Treasury would either gain or lose; Lie (2004) mentioned increased risk of interference, heightened competition concerns (especially with regard to spectrum hoarding), higher transaction costs in assembling spectrum bands in contiguous areas, increased difficulties in realizing welfare benefits resulting from international harmonization and standardization (cf. also Analysys et al., 2004; Cave et al., 2007; Hazlett, 2008b).[24] Moreover, vested interests are stronger in European and Anglo-Saxon countries, especially with regard to broadcasters, mobile network operators and public sector spectrum users.[25] In contrast, where spectrum is not extensively used, there are lower barriers to changing the status quo and a smaller degree of uncertainty. Therefore, the intensity of spectrum usage plays a crucial role in the decision between big-bang reforms and gradual reforms.

In the remainder of this sub-section, the model in Dewatripont and Roland (1995) is adapted to isolate the parametric conditions under which a big-bang DASS/DALL reform is preferable to gradual implementation of these reforms, given spectral encumbrance status. The notation used here is the same used in the original model, but R_1 and R_2 become *DASS* and *DALL*, respectively. The outcome generated by reform i (i=*DASS*, *DALL*) depends on a partition of the set of possible states of nature having N_i elements, the kth element being denoted by $s_{ik}\epsilon\{s_{i1}, s_{i2}, \ldots, s_{iNi}\}$; s_{DASSk} and s_{DALLm} denote the realized state for DASS and DALL; the costs of reversal are denoted by $-\xi_i$, with $\xi_i < 0$, when reform i is implemented alone and by $-\xi$, with $\xi < 0$, when both reforms are implemented.[26]

[23] In other words, any adverse signals from partial reform would not be so large as to warrant stopping the reform (cf. Dewatripont & Roland, 1995, p. 1211).

[24] Cave (2010) suggested that switching to a market method of allocating spectrum introduces incentives to resist forms of spectrum hoarding, which are likely to occur when regulatory constraints limit the substitutability of frequencies.

[25] See Kwerel and Williams (2002), Hazlett (2003) and Jackson (2011). See also Hazlett (2008a) and Ofcom (2007) on broadcasting; Cave (2010) on mobile (virtual) network operations; ERG and RSPG (2009) and Cave et al. (2007), Ch. 6 on windfall gains and losses.

[26] The following conditions are imposed: $\xi_{DASS}+\xi_{DALL}\leq\xi < \min\{\xi_{DASS}, \xi_{DALL}\}$. Also, realizations of states of nature for reform i are ranked according to the expected outcome of having both reforms implemented, given that s_{ik} has been realized. Note that DASS and DALL are independent and complementary reforms. See Dewatripont and Roland (1995) for additional details of their model.

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Assume the European and Anglo-Saxon cases can be distinguished from the others using $-\xi_i$ as a proxy for spectral encumbrance, because heavy spectral encumbrance implies greater reversal costs when adverse signals occur during the reform process (e.g., a high number of disputes for harmful interference or an insufficient number of trades for market liquidity).

A big-bang strategy leads to the expected payoff

$$BB = (1-\delta)E_{k,m}O(s_{DASSk}, s_{DALLm}) + \delta E_{k,m}\max\{\xi,\ O(s_{DASSk}, s_{DALLm})\}, \quad (1)$$

where δ is a discount factor ($\delta < 1$), and $E_{k,m}\ O(s_{DASSk}, s_{DALLm})$ is the expected outcome of both reforms before the realizations of either s_{DASSk} or s_{DALLm}.

The maximum expected payoff under a gradualist strategy, in which DASS is implemented before DALL, is denoted by $GR_{DASS,DALL}$. Assuming that DASS is associated with the realization s_{DASSk}, the decision to also implement DALL gives the expected payoff

$$DALL(s_{DASSk}) = (1-\delta)E_mO(s_{DASSk}, s_{DALLm}) + \delta E_m\max\{\xi,\ O(s_{DASSk}, s_{DALLm})\}, \quad (2)$$

where $E_m\ O(s_{DASSk}, s_{DALLm})$ is the expected outcome of implementing DALL (given that s_{DASSk} has been realized). It is also assumed that $DALL(s_{DASSk}) < \xi_{DASS}$ if $k < \underline{k}$, that is, if a signal with an index less than $\underline{k}$ is realized. The probability of $k < \underline{k}$ is $\Pr(k < \underline{k})$.

Thus, the expected payoff under gradualism is

$$GR_{DASS,DALL} = (1-\delta)E_kH(s_{DASSk}) + \delta\Pr(k < \underline{k})\xi_{DASS} + \delta\Pr(k \geq \underline{k})DALL(s_{DASSk}|k \geq \underline{k}), \quad (3)$$

where $E_kH(s_{DASSk})$ is the expected outcome after only DASS has been implemented, and s_{DASSk} is realized.

Proposition 1. $GR_{DASS,DALL} > BB$ if and only if

$$-\xi_{DASS} < T \equiv -DALL(s_{DASSk}|k < \underline{k}) - [(1-\delta)/\delta]\ [BB - E_kH(s_{DASSk})]/\Pr(k < \underline{k}).$$[27]

Proposition 1 shows that a necessary and sufficient condition for gradualism to dominate big-bang reforms is that the reversal cost of the first reform (for instance DASS) is less than the threshold T.

When $-\xi_{DASS}$ is high, $GR_{DASS,DALL} > BB$ when T is high enough. Given the value of δ, T increases — other things being equal — as: $DALL(s_{DASSk}|k < \underline{k})$ decreases; $BB - E_k\ H(s_{DASSk})$ decreases; or $\Pr(k < \underline{k})$ increases.

Arguably, in cases where spectrum is not heavily encumbered, $\Pr(k < \underline{k})$ is low, $BB - E_k\ H(s_{DASSk})$ is positive and relatively large, and $DALL(s_{DASSk}|k < \underline{k})$ is not too negative.[28] That is, where spectrum usage is not high, reversal cost is likely to fall above the threshold, and a gradual approach to reform is not preferable to a big-bang approach.

Finally, let δ vary. T is larger the higher the value of δ. Interpreting δ as the speed with which reforms are implemented, this means that the more rapid implementation is, the more likely a gradual approach is to be preferable to a big-bang approach.[29]

4.3. Reform complementarity

In general, spectrum trading has only a small impact on spectrum efficiency, if unaccompanied by flexible spectrum rights enabling change of use (cf. Valletti, 2001; Analysys et al., 2004; Hazlett & Muñoz, 2009). Our review of spectrum policies suggests that the two major reform packages — DASS and DALL — can be seen as complementary by regulators, who have considered that acting on both DASS and DALL (instead of only one) would accrue greater benefits. However, DALL has been more complex, and its progress has been slower. This lack of flexibility in changing spectrum use might explain, at least in part, why trades have been fewer than usually expected after DASS (cf. Xavier & Ypsilanti, 2006; Hazlett et al., 2007).

A more market-oriented design of licensees' spectrum rights might accrue Pareto-improving benefits in a manner similar to that experienced in economies in transition — notably China — through the so-called dual-track system (McMillan & Naughton, 1992; Roland, 2000, Ch. 6): current spectrum licensees would continue their traditional operations, while additional operations would be allowed initially at the margin, under licensees' responsibilities for interference control in their shared spectrum.[30] This method might help to develop — and increasingly rely upon — spectrum usage rights, rather than command-and-control regulation, for more efficient spectrum sharing (cf. Analysys et al., 2004; Baumol & Robyn, 2006; Holland et al., 2012).

There is, however, still little empirical evidence for the economic impact of DALL on interference (i.e., on its costs). A growing number of studies have suggested that new approaches should be used in designing license rules, especially in

[27] This can be easily shown by rewriting $GR_{DASS,DALL}$ in Eq. (3) as $GR_{DASS,DALL} = (1-\delta)\ E_kH(s_{DASSk}) + \delta BB + \delta\Pr(k < \underline{k})\ [\xi_{DASS} - DALL(s_{DASSk}|k < \underline{k})]$. Then, straightforward computations yield the thesis.

[28] $BB - E_k\ H(s_{DASSk})$ is likely to be greater than $BB - E_k\ H(s_{DALLk})$, because DALL brings about the larger share of expected welfare benefits (cf., e.g., Analysys et al., 2004).

[29] As δ approaches 1, the condition collapses onto $-\xi_{DASS} < -DALL(s_{DASSk} \mid k < \underline{k})$; that is, gradualism is always better than big bang, provided that informative reforms are quickly implemented one after the other. At the opposite extreme, as δ tends to zero, it becomes increasingly more difficult to have the condition satisfied; that is, when reforms are very slow, big bang can yield a larger benefit as compared to gradualism.

[30] The Licensed/Authorized Shared Access regulatory approaches (LSA/ASA) aim to allow licensed IMT spectrum to be used by more than one entity (RSPG, 2011).

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defining interference parameters to favor greater technology and service neutrality in spectrum access (Webb, 2009; Kwerel & Williams, 2010; Cave & Webb, 2012). Successful design and implementation of those rights could constitute a major step forward in the evolution of DASS and DALL reforms, as the informational burden would be centered on license holders. Eventually, decisions on spectrum use would be fully delegated to informed license holders, and interference problems would be more efficiently internalized.

The following subsection will return to reform complementarity to discuss its implications for sequencing.

4.4. Reform sequencing

Transition economics shows that an incorrect sequence of reforms can be costly, even when reversal to the status quo is possible, because reversal costs are incurred, and the implementation of a better reform sequence is delayed.[31] In countries where spectrum management reform has taken a gradual approach, effective deregulation of license conditions toward technology and service neutrality (i.e., DALL) has not preceded DASS. This sequence might be explained by considering that DASS has a limited impact on interference control and spectrum rights (traditionally designed by the regulator); that is, DASS costs less than DALL and is relatively easier to implement.

Transition economics provides a deeper analysis, especially regarding those propositions which focus on the implementation of complementary reform packages under uncertainty. Those propositions show that the strong complementarity of reform packages, such as DASS and DALL, can make gradualism optimal and that "if partial reforms are unstable, the choice at each stage of transition is between accepting the next reform or reversing the previous ones" (Dewatripont & Roland, 1995, p. 1209). On the one hand, DASS alone has features of an unstable reform: in particular, anti-competitive behavior and spectrum pre-emption remain possible, for instance, by means of spectrum hoarding; spectrum regulators can establish ex ante safeguards (e.g. by setting spectrum caps, which have been applied in some countries), but allowing change of use (by DALL) is more effective than regulation in promoting spectrum efficiency dynamically (Cave, 2010). On the other hand, regulatory intervention to avoid or to correct unwanted outcomes can be seen, in the transition economics perspective, as a costly reversal of a reform aimed at developing spectrum markets.

The above considerations support: (a) a gradual, rather than a big-bang approach, at the onset of spectrum management reforms (in the circumstances discussed above); and (b) implementing DALL, in situations where DASS has been introduced first (this avoids the drawbacks of enacting DASS alone and reaps the benefits of DASS/DALL complementarity). However, if DASS results in a large welfare loss, then the expected outcome of proceeding with DALL could be lower than that of reverting to command-and-control regulation after DASS; hence, a return to the status quo would be optimal in such cases.

From a normative perspective, transition economics can also be used to discuss whether (evolutionary) sequential reforms of spectrum management should begin with DASS or, in contrast, with DALL. A few results in Dewatripont and Roland (1995), Propositions 2–5 suggest that DALL should be the first reform package to be implemented. One reason for this order is that, if DALL has positive expected payoffs, it builds support for DASS, even if DASS is unattractive ex ante (as it can result in anti-competitive behavior and welfare losses).

Using the model, DASS should be implemented when $DASS(s_{DALLk}) > \xi_{DALL}$. Indeed, it might well be the case that, after DALL, the best thing to do is to implement DASS also, instead of bearing reversal cost ξ_{DALL} and losing the benefits of DALL. Thus, the welfare benefits of full DALL/DASS gradual reform would be realized. Moreover, as $-\xi_{DALL}$ is supposed to be high where spectrum is more encumbered, a full reform (with DALL first and DASS second) could be implemented more easily in countries where spectrum is more heavily used. Second, as the expected outcome of DALL is greater than that of DASS, it is better to start with DALL – other things being equal. The advantage of this sequencing is in terms of discounting, because of a better partial reform outcome after the first reform package (DALL) is implemented. Third, experiences from liberalizing countries, as well as the other studies mentioned above, support the view that – other things remaining equal – liberalization of allocation and establishment of property-like private rights over spectrum are riskier than merely changing the assignment procedures (either at the primary or secondary level). Accordingly, spectrum deregulation should begin with DALL rather than with DASS, because introducing the riskier reform first increases the option value of reversibility, which in turn increases the expected outcomes of reforms. It should however be noted that reform packages can differ in more than one of the aspects discussed above (e.g., risk and expected outcome), that might point toward different sequences of reform packages. When this is the case, there is little guidance on the optimum sequencing.

5. Conclusion

Spectrum regulators have been undertaking a complex task moving from administrative toward market-based methods of spectrum regulation, whilst managing uncertainties associated with possible outcomes in the reform process. Therefore, this study has considered current major spectrum policy reforms using the transition economics approach, which focuses on the comparative advantages and disadvantages of big-bang versus gradual reform strategies, as well as of alternative reform sequences (for gradual strategies). This has provided several new insights to spectrum management reforms.

[31] Existing analyses of the costs and benefits of spectrum policy reforms have not examined (or estimated) reversal costs, which are relevant in the formal analysis suggested in the transition economics literature.

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In the countries surveyed that have liberalized spectrum management, regulators have proceeded heterogeneously with their reforms, implementing varying strategies and tactics. Apart from the Central American reformers, the deregulation of spectrum management has happened gradually but at different speeds. An evolutionary approach has generally been adopted by regulators moving from command-and-control regulation to market-based mechanisms. In particular, implementation of more liberal methods of spectrum assignment (DASS) have usually preceded implementation of those of spectrum allocation (DALL), which have been more complex and slower than DASS.

This work has studied the reasons for those differences in strategies and tactics of deregulation of spectrum use as well as options to maximize the expected benefit of reforms. It found that, generally, the higher the usage is of available spectrum, the more appropriate it is that a gradual approach to spectrum management modernization is adopted. Indeed, the outcome of any big-bang reforms would be very uncertain in that situation, because of the large amount of information required to cope with the heavy legacy of command-and-control regulation. A gradual approach is preferable, if it offers options to deal with uncertainty better, by acting on reform sequencing to reduce uncertainty and to maximize expected payoff. With a gradual approach, information on both the impacts of partial reforms and the associated market environment can be collected prior to implementing additional reform measures, or reverting to the earlier state. Techno-economic information regarding current and prospective spectrum usage is key when making decisions about the liberalization process of spectrum management. For optimal implementation of reform policies, especially important is accurate analysis of the initial country-specific situation regarding spectrum usage; the expected outcomes of reform packages under either a big-bang or a gradual approach; and the actual outcomes of reforms in progress.

This work has identified the parametric conditions under which a big-bang reform is preferable to a gradual one, given the speed of reform. Above a certain threshold, reversal costs are likely to be excessive with a gradual approach and so a big-bang approach in that situation would be preferable.

This study also argues that effective deregulation of spectrum allocation should not be postponed, taking into account the complementarity of DALL/DASS and that DALL has higher expected benefits but is also riskier than DASS. In particular, the use of transition economics confirms that introducing DASS only (in the early stages of transition) yields, at best, only minor benefits.

Finally, this study provides suggestions for future work on spectrum liberalization. For instance, spectrum management reform could be more effective if progress could be achieved regarding more liberal spectrum allocation methods which take into account the magnitude of reversal costs. Relatively frequent reviews of spectrum strategies could further help to monitor progress and to steer reforms.

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