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Implications of dynamic spectrum management for regulation

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ABSTRACT

The Coase theorem suggests that a regulatory scheme, which clearly defines spectrum property rights and allows transactions between participants, induces an optimal spectrum assignment. This paper argues that the conditions required by Coase are gradually achieved by the introduction of Dynamic Spectrum Management (DSM), which enables a dynamic reassignment of spectrum bands at different times and places. DSM reduces the costs associated with spectrum transactions and thus provides an opportunity to enhance efficiency through voluntary transactions. This study analyzes the factors affecting the benefits of a regulatory scheme allowing transactions, compares and quantifies the potential gains associated with different spectrum regimes by employing agent-based simulations and suggests policy implications for spectrum regulation.

1. Introduction

The radio spectrum has become increasingly vital for modern communications. In fact, global mobile data traffic is expected to grow 11-fold between 2013 and 2018, reaching 1.4 mobile devices per capita by 2018 (Cisco, 2014). In a context of increasing scarcity, optimizing the assignment of radio spectrum has emerged as an important policy issue (Cave & Webb, 2012; Freyens, 2009; Ting, Wildman, & Bauer, 2005). This debate has led to the development of numerous proposals regarding new regulatory regimes. Currently, the most commonly adopted regulatory approach is the so-called *Command and Control*, which assigns spectrum on an exclusive basis to an operator, through a centralized mechanism, including auctions. Under this regime, the government decides both on the type of use (allocation) and on the operator for the frequencies (assignment) in a centralized fashion and it usually allows no market-based reassignment of the spectrum. Another regime, the *Commons*, allocates part of the spectrum (e.g. the industrial, scientific and medical (ISM) band) on an unlicensed basis for free access. More recently, a *Property Rights* approach has been introduced in some countries, including some with large markets, such as the UK. This regime allows spectrum transactions between operators, market-based reassignment and reallocation of the spectrum (e.g. service neutrality).

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The effect of market-based regimes on competition and efficiency is debatable, due to the variety of practical implementations. Thus, whilst a property right regime has had low impact on new firms entry in New Zealand and Australia (MED, 2005; ITU, 2003a), it has had a considerable impact in Guatemala (ITU, 2003b).

On grounds of economic efficiency, Coase (1959, 1960) first recognized that well defined property rights help solve externality problems. The application of the Coase theorem to the current spectrum policy debate suggests that, as the spectrum is valued differently by agents, a sufficiently low transaction cost and clearly defined property rights induce transactions which result in an efficient outcome, regardless of the initial spectrum assignment. In turn, if transaction costs are high, the social optimum is attained when a spectrum band is assigned to the agent that values it the most. A central entity (e.g. government) can assign the spectrum if it is aware of these valuations. However, if it lacks this information, it should find a mechanism to make the agents reveal their valuations (e.g. auctions). In any event, a centralized decision leads to inefficient assignment over time if valuations change or if the criteria to assign the spectrum improperly reveal preferences (e.g. *beauty contests*). Moreover, in the case of a suboptimal initial assignment, subsequent transactions can lead to an optimal assignment in a Coasean scheme, because reassignments are mutually beneficial.

A regulation that defines spectrum property rights and enables transactions is limited by the technology, because of the complexity of radio access and interference management. Recently developed radio access capabilities address these issues and, at the same time, several national regulatory authorities (NRA) are currently introducing the option of trading in spectrum licenses.

In particular, the development of Dynamic Spectrum Management (DSM) technologies, such as Cognitive Radio Systems (CRS) (ITU Report ITU-R M.2225, 2011), may constitute a significant step towards facilitating transactions, since they enable spectrum band reassignments at different times and places in a dynamic fashion. In CRS, several deployment scenarios have been identified, such as (i) managing dynamically and jointly the resources of the deployed radio access technologies (RAT) of the mobile network operator, to adapt the network to the dynamic behavior of the traffic and to maximize the capacity; (ii) improving the spectrum efficiency by exploiting the unused spectrum for cooperative spectrum access at a specific location and time; and (iii) accessing spectrum in bands shared with other radio-communication services by identifying unused spectrum resulting from traffic variations by means of CRS capabilities (e.g. use of white spaces).

Thus, DSM offers a great potential by allowing market mechanisms, which detect the value of the spectrum at different times and places. DSM aims to use the spectrum *holes*, which are points in frequency, time and space unoccupied by any transmission. Furthermore, DSM may allow to compare different spectrum valuations in real-time to assign it to the users who value it the most and thus induce further transactions. DSM may not bring any significant effect within a static spectrum regime, which maintains the ownership conditions in time and location. However, a flexible regime may require DSM to reassign the spectrum in a dynamic fashion.

Several authors highlight the benefits of a spectrum regime that includes tradability of rights and higher flexibility in interference management (Cave & Webb, 2012; Freyens, 2009; Ting et al., 2005). Other researchers study how DSM may increase spectrum efficiency (Attar, Ghorashi, Sooriyabandara, & Aghvami, 2008; Crocioni & Franzoni, 2011; Freyens & Yerokhin, 2011; Raychaudhuri, Jing, Seskar, Le, & Evans, 2008), the feasibility of different business scenarios for DSM (Grønsund, Grøndalen, & Lähteenoja, 2013; Sayrac, Uryga, Bocquet, Cordier, & Grimoud, 2013) and the importance of regulation and standardization (Baldini et al., 2013; Durantini & Martino, 2013).

Interference management has been until the date either too restrictive, such as in an exclusive regime which allows no other operators to interfere, or too relaxed, such as in a commons regime in which interference precludes assuring quality of service (QoS). The optimal interference level, which is usually higher than zero and depends on the service requirements, leads to an optimal usage of the spectrum. Diversity in service demand may indicate that a flexible spectrum regime can bring benefits by creating a diversified supply of spectrum, which incentivizes quality differentiation through transactions. Under flexible spectrum regimes, a portion of spectrum could be assigned under different interference levels for different services. This is facilitated by DSM, which permits a precise control of interference parameters, i.e., the quality of the service.

The effects of a regulatory regime, which facilitates transactions, are not yet fully understood in a context of changing spectrum valuations.[1] The purpose of this paper is to analyze the potential of DSM to increase social welfare, when applied under a spectrum regime that considers the dynamic value of the spectrum and implements a spectrum market in a context of clearly defined property rights and zero costs of spectrum transactions. In concrete, this work aims to acquire an approximate value on the social gains of employing DSM under such a regime.

This study defines the spectrum value by its ability to fulfill user requirements, which present volatility in terms of required capacity and quality. In other words, the spectrum value depends on its specific use. The paper employs agent-based modeling (ABM)[2] to simulate the dynamic behavior of ICT agents, both operators and end users. ABM is especially suitable for analyzing the behavior of agents and the collective effect of their interaction. These simulations illustrate and quantify the advantages of a flexible spectrum regime, assuming the conditions of the Coase theorem that are likely achieved by the introduction of DSM, current characteristics of mobile traffic and a competitive market, which includes different type of operators.

[1] One theoretical approach has been performed by Freyens and Jones (2014).

[2] For more information on ABM see Tesfatsion and Judd (2006).