Information Economics and Policy 37 (2016) 34–41

Contents lists available at ScienceDirect

Information Economics and Policy

journal homepage: www.elsevier.com/locate/iep

Spectrum policy and competition in mobile data

Gorm A. Grønnevet[1], Bjørn Hansen[1], Bjørn-Atle Reme[1,*]

Telenor Research, Building D, Snarøyveien 30, 1360 Fornebu, Norway

A R T I C L E   I N F O

Article history:
Received 5 February 2015
Revised 25 May 2016
Accepted 28 July 2016
Available online 29 July 2016

JEL classification:
L13
L51
L96

A B S T R A C T

This paper studies the effects of radio spectrum sharing between two mobile operators within a Hotelling model of duopoly. We apply the M/M/1 queuing model to analyze the effect of mandated sharing of radio spectrum on the equilibrium connection quality, data volumes and prices. Our analysis shows that spectrum sharing can have adverse effects. First, it creates an incentive for the mobile operators to increase the load in their network in order to weaken the competitor. A higher network load leads to more network congestion and suboptimal equilibrium connection quality. Second, consumer surplus decreases and industry profit increases for a wide range of parameter values in the model. In other words, spectrum sharing could lead to a transfer from consumers to producers.

1. Introduction

The introduction of the smartphone in 2008 led to a tremendous growth in the demand for mobile data. This growth is expected to continue for many years to come as the use of internet services becomes ever more mobile.[2] At the same time the supply, the amount of spectrum licensed for transmitting mobile data, will not experience a comparable growth. In response to this development, new technologies and regulatory remedies are being considered in order to ensure a more efficient utilization of the spectrum resource. For example, The European Union has mandated its member states to promote spectrum sharing among owners of spectrum.[3] Some countries already have clauses on spectrum sharing included in the 4G license text.[4]

An important argument in favour of spectrum sharing is that it will result in a welfare improvement since a scarce resource, spectrum, is utilized more intensely. There is however one important aspect missing in this line of argument: how the owners' strategic incentives regarding spectrum utilization, and hence the market equilibrium, is affected. This paper is the first to apply the M/M/1 queuing model to a Hotelling duopoly model for studying strategic interaction in a stylized spectrum sharing scenario: two identical mobile operators, fixed capacities and no firm entry.[5]

Letting the mobile operators set the prices and qualities of their services we find a counter-intuitive result: spectrum sharing can lead to higher end-user prices and lower consumer surplus. The intutition for the adverse effects of spectrum sharing is directly related to the strategic effects: the mobile operators' capacities become interrelated when unused capacity can be utilized by a rival. This creates an incentive to increase network load in order to weaken the competitor. A higher network load creates congestion, which harms consumers by reducing connection quality. Within our model we also analyse the effect on social welfare from two different spectrum sharing regimes: mandated free sharing, where unused capacity is made available free of charge, and a spectrum trading regime where network operators can buy and sell unused capacity.

The landmark contribution when it comes to spectrum management is Coase (1959), which argues that the market mechanism will ensure an optimal use of spectrum, provided that owner-

---

[*] Corresponding author.
E-mail addresses: Gorm-Andreas.Gronnevet@telenor.com (G.A. Grønnevet), Bjorn.Hansen@telenor.com (B. Hansen), Bjorn-Atle.Reme@telenor.com (B.-A. Reme).

[1] All authors are researchers at Telenor Research.

[2] According to Cisco (2013) global mobile data traffic grew 70 percent in 2012 and for Western Europe by 44 percent. Cisco projects an annual growth rate of 50 percent for the period 2013–2018.

[3] See EU (2012). A timeline for UK implementation is found in figure 14 of OFCOM (2013). See also European Commission (2012).

[4] The recent spectrum auctions in Norway and Sweden contain a clause on spectrum sharing (see clause 2 in NPT, 2013 and section 2.8.3 in PTS, 2010).

[5] The model analysis focuses on spectrum sharing between competitors. Another situation could be one where spectrum is made available by firms which are not active in the same market, for instance broadcasters ("white spaces"). Even though our model does not explicitly consider such a situation, the main mechanism described in this paper also applies in this setting as long as there are at least two competing players in the mobile market.

http://dx.doi.org/10.1016/j.infoecopol.2016.07.003
0167-6245/

ship rights are allocated and transaction costs are sufficiently low.[6] Since 1959, regulating authorities in the US, Europe, and most other countries of the world have gradually implemented this prescription using spectrum auctions.

There are several other papers analyzing different aspects of spectrum management, for instance different hybrid regimes of licensed and unlicensed spectrum (e.g. Freyens, 2009), mechanisms for avoiding the "tragedy of the commons" in unlicensed spectrum (e.g. Bykowsky et al., 2010), trading in secondary spectrum markets (e.g. Bykowsky, 2003; Cave, 2010; Crocioni, 2009).[7] There are also papers which study imperfect competition for end-users in secondary spectrum markets (e.g. Kim et al., 2011 and Duan et al., 2010). In addition to the literature on spectrum management, our paper is inspired by recent papers using the M/M/1 queuing model for studying economic interaction (Bourreau et al., 2015; Choi and Kim, 2010). The contribution of our paper is to combine the M/M/1 queuing model with a model of imperfect competition for studying spectrum sharing between mobile operators.

Our finding that spectrum sharing creates a strategic incentive to increase network load in order to weaken a competitor has similarities to "spectrum hoarding" discussed by Cave (2010): to prevent "spectrum hoarding" regulators may demand the surrender of unused spectrum ("use-it-or-lose-it" clause). Such clauses incentivize firms to increase network load in order to avoid losing their acquired spectrum resource. This result is identical to what we find. The mechanism is however fundamentally different: whereas Cave (2010) focus on how "spectrum hoarding" restricts competition by preventing entry, we focus on how spectrum sharing affects the competition between existing competitors in a market. We show how the increase in network load influences the market equilibrium product price and quality, a mechanism not found in Cave (2010). Moreover, by analyzing spectrum sharing within a model we can present a more structured analysis of the mechanisms driving equilibrium prices, quality and welfare.

From here the paper proceeds as follows. Section 2 presents how network congestion and consumer demand is modeled. Section 3 develops the welfare maximizing benchmark while Section 4 solves the model assuming a regulatory regime where unused spectrum resources are made available to the competitor free of charge. In Section 5 we analyze the game assuming the providers can trade unused spectrum resources, and in Section 6 solutions are compared based on a numerical example. Finally, in Section 7 we conclude.

2. The model

This section presents the model framework used for the analysis. In order to derive consumer demand for mobile networks we need a measure of network quality. We first show how network congestion and quality is modelled, then derive consumer utility and demand as a function of prices and network quality.

2.1. Modeling network congestion

For a given capacity in a mobile network, there is a tradeoff between the number of customers served and average waiting time (speed). We formalize this by deploying the $M/M/1$ queuing model.

Consider a network i with capacity K_i, number of customers s_i, and data volume per customer equal to y_i. Using the $M/M/1$ queuing model, the average waiting time on network i is[8]

$$\overline{w}_i = \frac{1}{K_i - s_i y_i}. \tag{1}$$

Following Bourreau et al. (2015), we assume that connection quality is the inverse of waiting time, i.e.

$$\bar{q}_i = \frac{1}{\overline{w}_i} = K_i - s_i y_i. \tag{2}$$

Consider now a hypothetical situation where there are two networks, $i = 1, 2$ whose capacities are pooled. This is a situation with perfect, or frictionless, spectrum sharing where traffic from the two networks enters the same queue, and is served on a first-come, first-served basis. Again, using the M/M/1 queuing model we get average waiting time

$$\overline{w} = \frac{1}{K_i + K_j - s_i y_i - s_j y_j}, \tag{3}$$

where $i, j = 1, 2$ and $j \neq i$. Notice that if the networks are identical, $\overline{w} = 1/2\overline{w}_i$, hence average waiting time is halved by pooling.[9] The connection quality of the shared network is

$$\overline{q} = K_i + K_j - s_i y_i - s_j y_j. \tag{4}$$

Let $\theta \in [0, 1]$ be a parameter describing the technical efficiency of spectrum sharing across the two networks. The two extremes, $\theta = 0$ and $\theta = 1$, have straightforward interpretations; seperate networks and pooled network capacity. For $0 < \theta < 1$ we think of the model as a reduced form approach capturing the technical efficiency of the sharing technology. The connection quality of network i can be described by

$$q_i = K_i - s_i y_i + \theta\left(K_j - s_j y_j\right). \tag{5}$$

Thus, as described above

$$q_i = \begin{cases} \overline{q}_i & \text{if } \theta = 0 \\ \overline{q} & \text{if } \theta = 1 \end{cases}. \tag{6}$$

Notice that the parameter θ is exogenous to our model. In Section 6 we investigate how our results depend upon this efficiency parameter and the implications of assuming θ as endogenously determined. The two networks have $N = s_i + s_j$ customers in total. For simplicity, and without loss of generality, we normalize the market size (N) to unity in our model. This normalization also allows us to interpret s_i as the market share of network i.

2.2. Consumer utility and demand

We consider a market with two competing networks, $i = 1, 2$, selling network access to consumers. The consumers' utility of buying mobile data is a function of two product attributes: download volume (y_i) and connection quality (q_i). We use a special case of the Cobb-Douglas function to capture an important feature: data volume is worthless without connection quality, and vice versa. In addition, the marginal utility of one attribute increases in the level of the other. In the analysis we use a particular parametric form for this utility function:

$$u_i = v + y_i q_i, \tag{7}$$

where v denotes a base utility of the service.[10]

---

[6] In our model we do not focus on the role of transaction costs. This does not imply that transaction costs are unimportant in telecom markets. As pointed out by Coase, they play a crucial role for how efficient the market mechanism is.

[7] See also Valletti (2001); Xavier and Ypsilanti (2006) and Mayo and Wallsten (2010) for relevant discussions of spectrum trading. Other related papers are Freyens and Jones (2014) and Levy et al. (2013) which study the welfare effects of competition and increased congestion in the case of broadcasting.

[8] We assume that $K_i - s_i y_i > 0$.

[9] This is a property of the M/M/1-model which arises due to an aggregation effect: the probability of a traffic peak in both networks simultaneously is lower than in the probability of a traffic peak in a single network.

[10] v is necessary for ensuring positive net utility for the consumers in the model. In particular, we must assume throughout the paper that $v > \frac{1}{2}\left(3t + K^2\theta + K^2\right)$.