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Roaming and Investments in the Mobile Internet Market

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Abstract

This model discusses mobile network operators' (MNOs) incentives to invest in their network facilities such as new 4G networks under various regimes of data roaming charge regulation. Given an induced externality of investments (spillovers) due to the roaming agreements it will be shown that MNOs, competing on investments, widely set higher investments for below cost regulation of roaming charges. Otherwise, if MNOs are free to collaborate on investments, they set higher investment levels for above cost roaming charges. Both below- and above cost charges may be preferred from a welfare perspective. Furthermore, the paper discusses effects of the roaming charge regulation on roaming quality and MNOs' coverage.

Keywords: mobile Internet; investment spillover; national roaming; regulation

JEL-Classification: L22, L51, L96

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1 Introduction

The telecommunications industry faces the transition from third generation (3G) to 4G networks such as Long-Term-Evolution networks (LTE). "The boom in data traffic has caused mobile operators a lot of problems, because they need to invest in their existing 3G infrastructure and soon in new technologies like LTE and Wimax while maintaining parallel technologies like GSM (and in some cases CDMA)," says Uwe Steffen, the head of Nokia Siemens network's radio access solutions. The demand for mobile data traffic is persistently increasing throughout recent years. Global mobile data traffic grew 2.3-fold in 2011, mobile data traffic was more than three times greater than total Internet traffic in 2000.[1] Multimedia content through 3G services requires significantly larger capacities than voice or text messages through 2G, though. An email is normally between 1 and 50 KB, a page of an online newspaper can be 100 KB or more. The download of a song requires 2 to 5 MBs of data.

Hence, the transition from 2G to 3G and the rollout of LTE and Wimax networks, also referred as 4G, causes mobile network operators (MNOs) to consider new infrastructure models. Network operators begin to collaborate on infrastructure building or rely on infrastructure or network sharing. Collaborations on infrastructure tend to play a key role in the rollout of 4G. In Spain and Sweden networks already collobarate in building capacities for the new standards. In Germany, the incumbent operator Deutsche Telekom recently stated it would be open for collaborations in building up the fast LTE-Networks.[2] Under certain restrictions also the Bundesnetzagentur (the national regulatory authority) would embrace such collaborations among competitors (Bundesnetzagentur, 2010).

Network sharing as an infrastructure model can be implemented at different levels of a mobile network. It may take form of passive sharing of masts and antennas or sharing active elements of radio active access networks (RNAs) or roaming in the core of the network.[3] The present paper focuses on

[1] http://www.cisco.com/en/US/solutions/collateral/ns341/ns525/ns537/ns705/ns827/white_paper_c11-520862.pdf.

[2] http://www.spiegel.de/wirtschaft/unternehmen/0,1518,723862,00.html.

[3] For an overview of alternative forms of network sharing and technical details see http://www.gsm.org/documents/gsma.pdf.

cross sharing of infrastructure in terms of national data roaming. National roaming is considered as a form of network sharing where MNOs in the same country code, which are usually direct competitors, use each others' networks. The agreement permits subscribers to roam onto a host network if the home network is not available in a particular location or in a time of congestion. This kind of agreement has especially been employed at the early stage of the 3G rollout and in peripheral areas. In the early 2000s operators in Europe (T-Mobile/ O2 in the UK and in Germany or Tele2/ Telia in Sweden) or Telstra/ 3 Australia in Australia entered into national roaming agreements to rollout 3G networks quickly, to provide services in rural areas with low subscriber density and to provide additional capacity in congested urban areas or in times of congestion. Likewise the 3G rollout national roaming agreements will likely become important in the 4G rollout.

Any agreement on collaboration and sharing of infrastructure is naturally of regulatory and competition authorities' interest. Collaborations are typically subject to Article 101 of the EU Treaty which defines criteria under which such agreements could be considered as anticompetitive, however, also allows for potential efficiency gains which are weighted against competitive harm. Referring to national roaming, two competition cases underpin the European Commission's current view on the potential impact of roaming on competition. In 2006 the European Commission found that the agreement between T-Mobile and O2 in Germany would restrict competition at the wholesale level with potential harmful effects in the downstream markets. According to the European Commission roaming would undermine infrastructure-based competition, since it would significantly limit competition on quality and transmission speed. Moreover, it would reduce scope for price competition at the retail level. The European Court of First Instance finally annulled the decision holding that the European Commission had not presented sufficient evidence of harmful effects on competition. However, it generally agreed that national roaming agreement may limit competition between operators, in particular when roaming occurs in urban areas or markets which can take more than one or two operators. The link between roaming agreements and their induced effects on competition on infrastructure building and competition on retail prices serves as the starting point of the present paper. It takes a roaming agreement between two MNOs, competing on the retail level and possibly competing or collaborating on investments, as given and analyzes its impact on providers' incentives to invest in infrastructure.

Hitherto regulators tend to rely on operators to engage in negotiations to set a wholesale roaming price on each others' networks. Due to cross sharing of infrastructure the roaming charge for data services shows some similarities to widely analyzed two-way externalities in voice telecommunications. The effect of wholesale prices on competition and its regulation is extensively debated in the literature of voice telephony but is rarely addressed with data services, yet. The recent academic literature on voice telecommunications discusses the regulatory concerns under two-way network competition, where networks may use the termination charge as an instrument of tacit collusion because of a raise-each-other's-cost effect (see Armstrong, 1998; Laffont, Rey, & Tirole, 1998). Fabrizi and Wertlen (2008) stress, though, that interconnection agreements within the mobile Internet services do not have entirely the same nature as interconnection agreements between voice communications operators. With voice telephony interconnection refers to enabling end-to-end users telecommunications traffic, which thus involves the origination of a given traffic within a network, its transportation, and its termination either in the same or the rival network. Data roaming instead refers to the access of the unilateral service by the rival network, origination and termination. The present model shows that although operators negotiate roaming charges above costs this does not necessarily harm retail competition, since the effects of roaming charges on investments in network quality have additionally to be considered. Investment incentives may be encouraged both by high and low roaming charges. Moreover, both roaming charges above and below costs might lead to under- and overinvestments from a welfare perspective.

Recent research on roaming in the mobile Internet market is conducted by Fabrizi and Wertlen (2008). Their focus is on optimal market coverage given roaming agreements among networks. In their model MNOs are free to enter sharing agreements. They show that MNOs avoid network duplication in order to maximize rents from roaming. Valletti (2003) considers national roaming for mobile telephony and shows that only colluding operators have an incentive to engage in roaming agreements. The present model is in line with Valletti and Cambini (2005), who analyze voice communications providers' incentives to invest given different regulation regimes. In their two-way access model, networks tend to underinvest in quality, which is exacerbated if they can negotiate reciprocal termination charges above costs. The present model is on one-way access and builds up on a model of Foros, Hansen, and Sand (2002), who analyze demand-spillovers due to voice roaming and joint investments in the mobile voice communications market. They abstract from any wholesale pricing and regulation of roaming charges and show that under collusion on investments, firms' and a welfare maximizing regulator's interest coincide, whereas with noncooperative investments, firms even overinvest. The present model extends the model of Foros et al. (2002) by analyzing data traffic and wholesale regulation of roaming charges.

The paper is organized as follows: Section 2 describes the basic model. Section 3 solves the equilibrium in the retail market, whereas Section 4 analyzes incentives to invest given different roaming charge regulation regimes. Section 5 provides a social welfare analysis. Section 6 provides two extensions of the basic model, where MNOs choose the roaming quality and decide on their geographical coverage. Section 7 concludes.

2 The basic model

The model analyzes MNOs' incentives to invest in their network quality, where networks may collaborate on infrastructure investments, given different regulation regimes of roaming charge regulation. The following timing is assumed:

Stage 1: The roaming charge a is set by a regulator or is jointly determined by the MNOs.

Stage 2: MNOs choose the investment levels x noncooperatively or jointly.

Stage 3: MNOs compete à la Cournot in the retail market.

The choice whether networks cooperate when determining their investment levels will depend on whether it would be approved by the competition authorities.[4] The choices at stage 2 are fairly similar to those in the seminal models of R&D-spillovers of d'Aspremont and Jacquemin (1988) and Kamien, Muller, and Zang (1992). They analyze cost-reducing spillovers, whereas the present model analyzes demand-enhancing spillovers.

In line with Foros et al. (2002), Foros (2004), and Nitsche and Wiethaus (2011) the present model assumes Cournot competition in the downstream market, which seems reasonable since the networks face technological and physical constraints in spectrum capacity, for example, in the 3G-system. Moreover, MNOs must choose capacity levels, which are either built or rented in both the backbone or the access network, prior to competition in the downstream market (see Foros (2004) for mobile communications networks or Crémer, Rey, and Tirole (2000) for fixed-line communications networks). The presence of roaming agreements between MNOs is an indicator that networks face capacity constraints. MNOs can invest in the capacity, for example, to decrease download times or decrease congestion problems in order to increase user's perceived quality of the network.

The optimal roaming charge assumes that roaming charges are set before investments take place. Clearly, a regulator may not credibly commit ex ante to regulated roaming charges before investment decisions of the networks. However, without commitment a regulator may want to change roaming charges ex post. In this case, the optimal roaming charge would take investments as given. The common regulatory system of long run incremental costs is clearly designed to take investments consideration of networks into account. Moreover, given appropriate legal and regulatory institutions, commitment should be less of a problem.

2.1 Demand side

Consumers seek access to the mobile Internet while traveling in territory and have subscribed to one of two MNOs. MNOs compete in a territory along a line of a length normalized to 1. MNO 1's radio base station is located in the left part of the interval and MNO 2's base station is located in the right

[4] By the block exception of Article 101 (3) of the European Treaty, agreements which contribute to improving the production or distribution of goods or to promoting technical or economic progress while allowing consumers a fair share of the resulting benefit will be approved.

part of the interval. The coverage is taken as fixed in the base model.[5] MNO 1 serves an area of size α_1 and MNO 2 an area of size α_2. It is assumed that there are no white spots which are not covered, moreover, there might be an overlap where both MNOs are active. Investments by MNO i enhance its own quality but due to the roaming policy also the perceived quality of the rival MNO j. Following Foros et al. (2002), the total quality offered to consumers by MNO i can be written as

$$v_i = v + x_i + \beta x_j, \tag{1}$$

where v is an exogenous quality of the networks. The variable x_i represents the investment undertaken by MNO i and x_j the investment decision by the rival. A spillover parameter β, comprised between 0 and 1, describes the quality of roaming.[6] It indicates the impact of the investment by MNO j onto the demand of MNO i. If $\beta = 0$ the quality of roaming is so bad that users are not able to access data in a host network, otherwise for $\beta = 1$ quality is similarly perfect for fellow and rival subscribers. Intermediate values may be interpreted as a fraction of download speed for rival customers roaming on a host network compared to fellow customers. The degree of the spillover is taken as fixed in the base model. MNOs may strategically set the degree of investment spillovers in an extension to the base model of section 6.1.

The inverse demand faced by MNO i is given by

$$p_i = v_i - q_i - q_j, \tag{2}$$

where p_i indicates the subscription fee (for example, a monthly fee) and q_i the total mobile traffic by subscribers of network i. In the presence of spillovers, investment in the infrastructure of MNO i enhances the willingness to pay for both MNOs.

[5] In an extension of section 6.2 providers decide on expanding their coverage.

[6] Comparably, Valletti (2003) introduces a quality parameter of roaming to describe a customer's perceived coverage.

2.2 Supply side

For creating mobile data services MNOs face the same constant per unit cost c at the wholesale level, any other costs at the retail level are normalized to zero. MNOs pay each other a roaming charge a for cross access whenever a subscriber of MNO i roams on the host network j. Roaming with data services generally differs from interconnection in telecommunications markets. In telecommunications markets interconnection refers to a two-way access problem where both provides have to interconnect to terminate calls and thus, pay each other a reciprocal interconnection (or termination) fee. Roaming instead generally refers to a one-way problem, where one operator which does not operate in a respective territory uses the entire service of another operator which covers this territory. Therefore, the inactive operator pays the active operator a roaming fee (but not vice versa). In the present setup, both operators only partially cover the territory and have to pay a roaming charge to each other to full service in the entire area. Thus, the present might be labeled as double-one-way.[7] The roaming charge might be either regulated or negotiated by the networks. In the present model networks are symmetric and negotiate a reciprocal roaming charge. Finally, each network incurs a convex cost of investments of $I(x_i) = \frac{1}{2}\delta x_i^2$, where δ is a scale parameter of investment costs, which is assumed to be sufficiently large to allow for stable equilibria:

Assumption 1: $\delta > max[\frac{1}{2}(1+\beta)^2, \frac{2}{9}(5+5\beta^2-8\beta)]$.

The critical values are derived below. The threshold value on investment costs (δ) guaranties equilibrium existence and interior solutions for the choice of the investment level and of the roaming charge. Without this assumption there might be an escalation of investments.

3 Retail market

It is assumed that MNOs have symmetrically patronized users in some previous stage to this game. In the third and last stage the networks compete à

[7]This labeling refers to an anonymous referee.

la Cournot in the retail market given a fixed roaming charge and investment decisions of the previous stages. The MNOs solve

$$\max_{q_i} = \pi_i - I(x_i),$$

with

$$\pi_i = \alpha_i(p_i - c)q_i + (1 - \alpha_i)(p_i - a)q_i + (1 - \alpha_j)(a - c)q_j. \quad (3)$$

Users are perfectly mobile within the entire market (of length 1) and seek access to the mobile Internet. The probability of being served by the subscribed network depends on its coverage. In a possible overlap, where both MNOs are active, users are served by the subscribed network. The profit consists of three components: (1) The net revenue from serving fellow subscribers whenever they are connected to their subscribed network. This happens with probability α_i; (2) The revenue when the fellow customers seek access in the rival's exclusive coverage $(1 - \alpha_i)$, net of the payment of the roaming charge a; (3) The revenue from serving rival customers seeking access into the own exclusive coverage $(1 - \alpha_j)$. Henceforth it is assumed that MNOs are perfectly symmetric and cover the same share of the market with $\alpha_i = \alpha_j = \alpha > \frac{1}{2}$ to ensure that the entire market is covered.

Equilibrium quantities[8] are obtained as

$$q_i^* = \frac{\alpha(a - c) + (v - a) + (2 - \beta)x_i - (1 - 2\beta)x_j}{3}. \quad (4)$$

Inserting equilibrium quantities into the demand function of Eq. (2) yields equilibrium subscription prices of

$$p_i^* = \frac{2(1 - \alpha)(a - c) + v + 2c + (2 - \beta)x_i - (1 - 2\beta)x_j}{3}. \quad (5)$$

The equilibrium retail quantity is decreasing in the roaming charge a, that is, $\frac{\partial q_i}{\partial a} < 0$. By increasing the cost of roaming, MNOs will decrease their quantity supplied to increase the price in the retail market. Hence, there will be an incentive to collude on the roaming charge to decrease quantities and increase profits. This is in line with the early literature on mobile communications (Armstrong, 1998; Laffont et al., 1998; Carter & Wright, 1999),

[8]The second order condition of $\frac{\partial^2 \Pi_i}{\partial q_i^2} = -2 < 0$ is always fulfilled.

which show that wholesale prices serve as a device to reach the collusive outcome at the retail level when networks compete in linear prices. By coordinating on high access prices, networks can achieve monopoly prices and do not bear any burden from high access prices if call traffic is symmetric.[9]

4 Investments

In style of the seminal papers of d'Aspremont and Jacquemin (1988) and Kamien et al. (1992) the model analyzes investment decision where MNOs may jointly set investment levels. The present model incorporates an additional stage to determine roaming charges for access to the rival's network. The model compares three different regulatory regimes: Cost-based regulation, above-cost regulation, and below-cost regulation. These regimes are compared to an outcome where providers are free to engage in negotiation over the roaming charge.

In the second stage MNOs determine their optimal investment level either noncooperatively by maximizing individual profits Π_i or jointly by maximizing $\widehat{\Pi} = \Pi_i + \Pi_j$ with respect to investment levels, where

$$\Pi_i = \left((v_i - c) - q_i^* - q_j^*\right) q_i^* - (1-\alpha)\left((a-c)(q_i^* - q_j^*)\right) - \frac{1}{2}\delta x_i^2. \qquad (6)$$

[9]With non-linear tariffs (for example, two-part tariffs) the problem of tacit collusion via access prices is reduced, since an increase in the linear price is compensated by a reduction of the fixed fee (see Armstrong, 1998; Laffont et al., 1998). Another strand of literature shows that networks may wish to coordinate on access prices below marginal costs if networks compete with two-part tariffs and price discriminate between on-net and off-net calls (Gans & King, 2001), or demand for subscription is elastic (Dessein, 2003). If not only the carrier but also the receiver benefits from calls Hermalin and Katz (2010) provide theoretical arguments for both access pricing above and below costs. Jeon, Laffont, and Tirole (2004), Berger (2005), and Hoernig (2007) analyze the impact of call externalities on equilibrium prices in mobile markets. The literature shows that MNOs coordinate on above-cost termination rates and implement large on-net/ off-net differentials to reduce competition at the retail level. Cambini and Valletti (2008) instead show that networks have reduced incentives to use off-net price discrimination when calls originated and received are complements in the information exchange. Armstrong and Wright (2009) and Harbord and Pagnozzi (2010) provide a comprehensive literature overview about cost-based and below-cost regulation.

4.1 Roaming charge regulated at costs

Suppose that the roaming charge is regulated to the marginal cost of providing mobile Internet services, that is, $a = c$. At stage 2 networks maximize their profits of Eq. (3) either individually or jointly. If both networks set their investment levels noncooperatively there exists a unique[10] (and symmetric) solution satisfying $\frac{\partial \Pi_i}{\partial x_i} = 0$ at

$$x_i^*|_{a=c} = \frac{v-c}{\frac{9}{2}\frac{\delta}{2-\beta} - (1+\beta)}. \tag{7}$$

When both networks choose investments cooperatively, they maximize their joint profit $\widehat{\Pi}$ with respect to x_i and x_j, which yields a unique[11] equilibrium investment level of

$$\widehat{x}_i|_{a=c} = \frac{v-c}{\frac{9}{2}\frac{\delta}{1+\beta} - (1+\beta)}, \tag{8}$$

where the asterisk indicates the noncooperative and the hat the joint solution.

Directly observe that equivalent to d'Aspremont and Jacquemin (1988), Kamien et al. (1992), and Foros et al. (2002) joint investments are higher than non-cooperative investments if $\beta > 0.5$. For $\beta < 0.5$ investments are strategic substitutes, otherwise they are strategic complements. The intuition for this result is provided by Kamien et al. (1992): If the spillover effect is small, then the demand effect experienced by network j as a consequence of MNO $i's$ investment is too small, compared to the demand increase of MNO j, so that the investment of the rival leads the demand and thus profits to decrease. Otherwise, for sufficiently large spillovers all MNOs benefit because total equilibrium profits increase and the demand of the rival MNO does not decline significantly.

[10]For the SOC to hold it has to be ensured that the costs of investments are sufficiently convex, that is, $\delta > \bar{\delta} = \frac{2}{9}(\beta - 2)^2$.

[11]In the cooperative setting, for the SOC to hold, it has to be assumed that $\delta > \hat{\delta} = \frac{2}{9}(5 + 5\beta^2 - 8\beta)$. This constitutes the second part of the above assumption, as $\hat{\delta} > \bar{\delta}$.

4.2 Roaming charge not regulated at costs

The more interesting case is a non-cost based regulation of roaming charges. Roaming charges can only be set at costs if a regulator knows demand and cost parameters. Although some sophisticated engineering network models are available, it is contentious in practice that a regulator can exactly set roaming charges at costs. Similar arguments hold for setting roaming charges above or below costs, though, except the regulator favors a roaming charge of zero.[12]

Suppose the roaming charge is not regulated at costs. With competition at the investment stage MNOs set investment levels of

$$x_i^* = \frac{(v-c) + \frac{1-\alpha}{2}\frac{8\beta-7}{2-\beta}(a-c)}{\frac{9}{2}\frac{\delta}{2-\beta} - (1+\beta)}, \tag{9}$$

whereas they jointly set investment levels of

$$\widehat{x}_i = \frac{(v-c) + \frac{1-\alpha}{2}(a-c)}{\frac{9}{2}\frac{\delta}{1+\beta} - (1+\beta)}. \tag{10}$$

When the roaming charge is regulated to the cost of providing mobile Internet service, MNOs do not take account of rival's demand in the roaming market, as the profit in Eq. (6) simply reduces to $\Pi_i = (v_i - c - q_i^* - q_j^*)q_i^* - \frac{1}{2}\delta x_i^2$. MNOs just balance the previously mentioned effects in the retail market. When incorporating roaming profits or deficits, though, MNOs have to take account of the induced demand of rival customers, which generates a profit or deficit from roaming depending on the regulation regime.

4.2.1 Joint investments

Consider that MNOs collaborate on investments. In a symmetric equilibrium, MNOs set investment levels of $x_i = x_j = x$, retail prices read as

$$p_i = \frac{1}{3}(v + 2a - 2\alpha(a-c) + (1+\beta)x). \tag{11}$$

[12] See section 5.

Retail prices are unambiguously increasing in investments, that is, $\frac{\partial p_i}{\partial x} > 0$ since subscribers' willingness to pay is increased. For an above cost roaming charge providers both benefit from higher retail prices and from an access markup in the roaming market and thus are willing to invest to enhance revenues in both markets.

However, below cost roaming charges lead to opposing effects. For larger investments fellow subscribers are more willing to pay, enabling providers to set higher prices in the retail market. However, also rival subscribers' willingness to pay is increased, leading to more roaming traffic by rival subscribers and thus to a deficit from each rival subscriber. Now, if MNOs jointly set investments they will perfectly internalize the effect of their investment on rival's demand. Simply observe from Eq. (10) that investments are higher for $(a > c)$ and are lower for $(a < c)$, independent of the investment spillover β. The effects are magnified by the amount of roaming in the market $(1 - \alpha)$. Thus, results are very straightforward: Compared to a regime of cost-based regulation MNOs invest more if the roaming charge is regulated above costs and invest less when roaming charge is regulated below costs.

4.2.2 Competition on investments

In case MNOs compete over investment levels they do not take account for the effect of their investment on the rival's demand. Hence, according to Eq. (9), the previous effects of above- and below cost roaming regulation may be reversed. For any investment spillover of $\beta < \frac{7}{8}$ MNOs invest less for above cost and invest more for below cost roaming charges. This confirms the result obtained by Valletti and Cambini (2005)[13] in their two-way access model if investment spillovers are not too large. As previously stated, investment decisions are strategic substitutes given sufficiently low spillovers, that is, $\frac{\partial x_i}{\partial x_j} < 0$. Thus, an increase of investments pushes the own demand and due to the Cournot-effect generally leads to a decrease of rival's de-

[13] Valletti and Cambini (2005) model a two-way access competition with two-part-tariffs. They provide robustness of their results in a companion article (Cambini & Valletti, 2003) when firms offer two-part discriminatory prices. Jeon and Hurkens (2008) instead show that MNOs can induce social efficient investment without distorting efficient pricing.

mand. Although income from roaming per rival subscriber increases, total roaming profit is reduced. This holds for a wide range of spillovers of $\beta < \frac{7}{8}$. For large investment spillovers of $\beta > \frac{7}{8}$ the Cournot-effect is dominated by the increase of total equilibrium profits, so investment turn to be strategic complements, that is, $\frac{\partial x_i}{\partial x_j} > 0$. Given sufficiently large investment spillovers, the result of Valletti and Cambini (2005) is reversed and competing MNOs decrease investment levels for below costs regulation. The effects are summarized in the following proposition:

Proposition 1. *If MNOs compete on investments, investment levels are higher (lower) for below (above) cost regulation of roaming charges if the investment spillover is not too large. Otherwise, if $\beta > \frac{7}{8}$, this result is reversed. If MNOs collaborate on investments, investment levels are higher (lower) for above (below) cost regulation independent of the extent of the investment spillover.*

Fig. 1 illustrates this proposition assuming a roaming charge of zero.[14] The solid line plots the noncooperatively determined investment levels and the dashed line shows the collusively determined one. Given sufficiently high spillovers ($\beta > 0.67$) joint investments will lead to higher levels than competition.

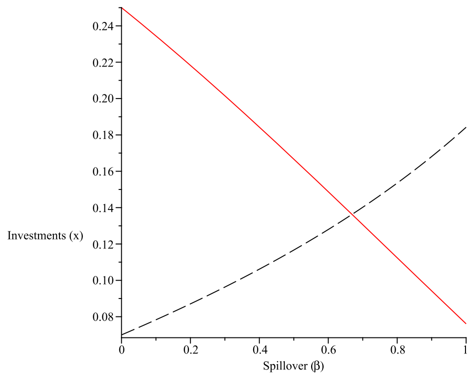

Figure 1: Competitive vs. collusive investment levels.

[14]The other parameters are set to: $\alpha = 0.75$; $c = 1$; $\delta = 3$; $v = 2$.

4.3 Negotiation over the roaming charge

Currently, many regulatory authorities tend to rely on operators to engage in negotiations to set a wholesale roaming price on each others' networks. The FCC recently required all wireless carriers to let customers of competing MNO's roam on their network. The mandate forces companies to reach at commercially reasonable terms for their roaming agreements, but the FCC doesn't itself set fees at this stage. Suppose providers negotiate over the roaming charge at stage 1 of the game.

Lemma 1. *In a symmetric equilibrium, MNOs negotiate a roaming charge above costs.*

Proof: See Appendix.

A negotiated above cost charge is in line with Valletti and Cambini (2005) in a model on voice telecommunications where it serves as a commitment devise not to fight over costly investments and in line with Fabrizi and Wertlen (2008) in a model on data roaming where it guarantees MNOs the appropriation of rents. Consider that a is set above costs. Taking the investment of the rival MNO j as given, MNO i is more reluctant to invest. If it increases its investment level, mobile traffic from fellow subscribers (q_i) would increase. According to the second part of the profit function of Eq. (6) this, however, reduces the benefit of above cost charges. Otherwise, if the investment spillover is sufficiently large, that is, $\beta > \frac{7}{8}$, investments push q_i and q_j in the above equation relative symmetrically, thus, the effects in the roaming market become relatively unimportant compared to the retail market and providers would be more willing to invest. In equilibrium, the investment-reduction effect dominates, though. The competitive investment level is denoted as

$$x_i^*|_{\hat{a}} = \frac{(v-c)(9\delta + 16\beta^3 - 12\beta^2 - 18\beta + 10)}{31\delta + 36\delta^2 - 10 + 8\beta - 16\beta^4 - 4\beta^3 + 30\beta^2 + 64\beta^2\delta - 130\beta\delta}. \quad (12)$$

To the contrary, if MNOs jointly set investment, an above cost roaming charge enhances investments unambiguously (see Eq. (10)) since MNOs are able to internalize the entire gain of an above-cost charge. Obviously, if they further jointly determine the roaming charge, they set a roaming charge above costs and so their profit maximizing investment level is given by

$$\widehat{x}_i|_{\widehat{a}} = \frac{v - c}{4\frac{\delta}{1+\beta} - (1 + \beta)}. \tag{13}$$

That is, if networks are free to engage in negotiations over the roaming charge they set larger investment levels in case they are also free to jointly determine investment levels, since $\widehat{x}_i|_{\widehat{a}} > x_i^*|_{\widehat{a}}$ for $\delta > \frac{1}{4}(1 + \beta)$, which holds given assumption 1. This is a quite interesting result from a competition policy and social welfare perspective. The above results imply, that if MNOs are free to negotiate an above cost roaming charge, an authority should also allow them to collaborate rather than to compete on investments. The question remains, how a benevolent social planner would ideally set roaming charges and investment levels.

5 Welfare analysis

The discussion above implies an important influence of roaming charges in order to enhance MNOs' incentives to investment. Given that it is in the interest of a regulator to encourage investments - which will be shown is the case - the authorities have to take account of both spillovers on investment and roaming charges.

Define total welfare as the sum of consumers' surplus (CS) and provider's profits, that is,

$$W = CS + \Pi_1 + \Pi_2, \tag{14}$$

with

$$CS = \frac{(q_1 + q_2)^2}{2}. \tag{15}$$

In the symmetric environment MNOs set quantities in equilibrium as

$$q_i^* = \frac{(v - c) - (1 - \alpha)(a - c) + (1 + \beta)x}{3}. \tag{16}$$

Hence, investments enhance consumer surplus. This simplifies the welfare analysis with respect to joint investments. Whenever joint investments increase retail quantities it should be preferred from a welfare perspective, as any joint decision naturally also increases MNOs' profits.

Taking into account MNOs' profits, due to the convexity of investments cost, there exists a welfare maximizing investment level[15] which solves $\frac{\partial W}{\partial x_i} = 0$ given as

$$x^w = \frac{v - c}{2\frac{\delta}{1+\beta} - (1+\beta)}. \tag{17}$$

To induce social optimal investments the social planner sets a below-cost roaming charge[16] by solving $\frac{\partial W}{\partial a} = 0$ of

$$a^w = c - \frac{\delta(v-c)}{(1-\alpha)(2\delta - (1+\beta)^2)} < c. \tag{18}$$

For marginal cost low enough the optimal roaming charge would be zero, since it cannot be negative.

A direct comparison of the social optimal investment level of (17) and the private optimal investment levels of Eqs. (13) and (12) yields that free negotiations over the roaming charge leads to a social underprovision of investments, that is, $x^w > \widehat{x}_i|_{\widehat{a}} > x_i^*|_{\widehat{a}}$.[17]

In the present setup free negotiations over the roaming charge, which, for example, is proposed by the FCC, run against the public interest. The divergence between the social and private optimal roaming charge and the resulting divergence in investment levels may serve as a rational for a regulatory intervention. It is unlikely in practice, however, that a regulator may directly influence MNOs' investments. It seems to be more relevant that a regulator may indirectly affect MNOs' investment levels by regulating the roaming charge below a cost level. Since the exact marginal costs of providing mobile Internet services are difficult to calculate, it seems to be a practical solution to implement zero charges, which the European Commission proposes in the long run for mobile voice communications services.

A comparison of the jointly and competitively determined investment levels of Eqs. (9) and (10) clearly shows that roaming charge regulation to

[15]The SOC of $\frac{\partial^2 W}{\partial x_i^2} < 0$ holds for $\delta > \frac{1}{4}(1+\beta)^2$, which holds given the restriction on δ.

[16]The SOC of $\frac{\partial^2 W}{\partial a^2} < 0$ is ensured given that $\delta > \frac{1}{2}(1+\beta)^2$, which constitutes the first part of the restriction on δ.

[17]Valletti and Cambini (2005) also provide an underinvestment feature if firms are left to negotiate a reciprocal access charge above cost. In the setting of Jeon and Hurkens (2008) firms reach a social optimal investment level for a cost-based access charge.

marginal costs, that is, $a = c$, leads to underprovision in the present model. A roaming charge of zero will further decrease joint investments levels, which leads to an even more severe social underprovision of investments.

However, if MNOs compete on investment levels, a roaming charge below marginal costs induce MNOs to increase their investment levels, given that the investment spillover is not too large ($\beta < \frac{7}{8}$). From a welfare perspective, a zero roaming charge regime may both lead to over- and underprovision as Fig. 2 indicates.[18]. The solid line plots the competitive investment level of Eq. (9) and the dashed line the welfare optimal investment level of Eq. (17). For sufficiently low investment spillovers, a zero roaming charge even induces overinvestment from a welfare perspective if MNOs determine their investments competitively, otherwise there is underprovision of investments.

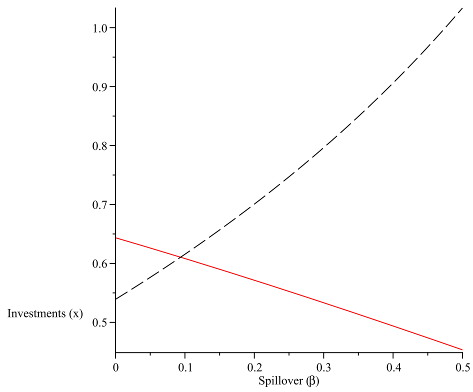

Figure 2: Roaming charge and welfare.

Proposition 2. *A social planner favors below cost roaming charges. A roaming charge of zero leads to underprovision of jointly set investment levels, whereas it may lead to both under- or even overprovision of investments if MNOs compete on investment levels.*

For low investment spillovers, MNOs' investments rarely affect rival consumers' willingness to pay. The positive effect on total demand and profits becomes relatively weak compared to the negative market share effect. As competition for market shares becomes relatively more important, this leads MNOs to engage in a race for investment which may even lead to overinvestment from a welfare perspective.

[18]Parameter values are set to $v = 4$, $\delta = 3$, $c = 1$, and $\alpha = 0.6$.

The different regimes of cooperative and noncooperative determination of investments demand a careful regulation of the roaming charge to reach socially preferred investment levels. With competition on investments in network infrastructure, a roaming charge below marginal costs widely encourage investments, where the opposite holds with joint investments. Thus, a regulator may both set a roaming charge below and above costs to reach an investment level, that is preferred from a welfare perspective.

6 Extensions

This section provides two extensions to the base model where providers additionally decide on the roaming quality and on coverage.

6.1 Roaming quality

This section allows MNOs to additionally decide on their optimal roaming quality (β). Networks may strategically determine the quality of data traffic of rival customers when roaming in their networks, for example, by downgrading the speed of interconnection compared to the speed offered by fellow subscribers.

Since a regulator can credibly commit on the regulation regime, the roaming quality is chosen after regulation is announced and before infrastructure investment takes place. The following sections analyze the impact of the roaming charge regulation on the MNOs' decision to invest in the roaming quality. To restrict the number of possible cases it is assumed that both infrastructure investments and roaming quality are either determined cooperatively or noncooperatively instead of a mixture of both decisions.[19]

6.1.1 Competition on roaming quality

Inserting the optimal retail quantity of Eq. (4) into the profit function of Eq. (3) yields the equilibrium retail profit, depending on the symmetric

[19]It seems reasonable to assume that whenever MNOs collaborate on investments they will additionally collaborate on the roaming quality and vice versa.

investment levels $x_i = x_j = x^*$ at the previous stage of

$$\Pi(x) = \frac{1}{9}\left(v - c + 2(1-\alpha)(a-c) + (1+\beta)x\right)\left(v - a + \alpha(a-c) + (1+\beta x)\right) - I(x). \tag{19}$$

Suppose MNOs compete on investments. Differentiation with respect to β implicitly determines the choice of the optimal roaming quality by

$$\frac{\partial \Pi^*}{\partial \beta} = \frac{2}{9}(1+\beta)\left((1+\alpha)(a-c) + v - c + 2(1+\beta)x^*\right) - \delta\frac{\partial x^*}{\partial \beta}. \tag{20}$$

To determine the optimal choice of β it is checked how infrastructure investments are affected.

Differentiation of Eq. (9) yields that the sign of $\frac{\partial x^*}{\partial \beta}$ is determined by

$$\frac{\partial x^*}{\partial \beta} = \underbrace{-x^*(9\delta - 2\beta^2 + 8\beta - 8)}_{<0}\underbrace{+(a-c)9(1-\alpha)}_{\lesseqgtr 0}. \tag{21}$$

Since investment costs are assumed to be sufficiently convex (δ is large), the first part of the equation is negative whereas the sign of the second part depends on the regime of the roaming charge regulation. For $a \leq c$ the second part is also negative, whereas it turns positive for a markup on marginal costs of $a > c$. In this case it depends on the level of the markup if the second positive effect outweighs the negative first one, so investments might increase in the roaming quality. In either case, investment levels are higher the higher the roaming charge. Hence, the regime of regulation determines MNOs' choice of the roaming quality. Simple observation of Eq. (20) shows that the impact on investment levels determines the optimal choice of the roaming quality.

The exact choice of the roaming quality depends on the convexity of the cost function. If MNOs face a deficit from roaming there are less incentives to increase the roaming quality. Being regulated below the cost of providing services MNOs face a deficit from roaming per rival subscriber. Now, an increase in the roaming quality increases the amount of roaming, and in turn the loss from roaming. The only incentive to increase the quality of roaming is due to the increase in the willingness to pay of fellow subscribers. Otherwise, if MNOs sufficiently benefit from roaming, they may even choose the maximal roaming quality. In case of a markup on costs they both benefit from an increased willingness to pay of fellow and rival subscribers. Consider for example parameter values of $v = 3$, $\delta = 4$, $c = 1$, and $\alpha = 0.75$. With a roaming charge of zero MNOs set a roaming quality of $\beta = 0.89$, with cost-based regulation they set $\beta = 0.98$, whereas they would set the maximal roaming quality of $\beta = 1$ for a 12% markup on the costs.

6.1.2 Collusion on roaming quality

Consider MNOs collaborate on investments and the quality of roaming. Simple observation of Eq. (10) shows that the infrastructure investment levels are unambiguously increasing in the roaming quality, independent of the type of roaming charge regulation. Contrary to competition on investment, the incentives to invest are higher the higher the roaming quality.

MNOs maximize their equilibrium profit with respect to the roaming quality, which reads as

$$\frac{\partial \widehat{\Pi}}{\partial \beta} = \frac{2\delta(1+\beta)((\alpha-1)(a-c)-2(v-c))^2}{(2\beta^2+4\beta-9\delta+2)^2} > 0. \tag{22}$$

Observe that the derivative is increasing over the interval of $\beta \in [0, 1]$. This confirms that the result of Foros et al. (2002) holds independent of regulation of wholesale charges. The equilibrium roaming quality corresponds to the maximal one. Again, when colluding, MNOs are able to internalize the roaming externality on individual profits. Otherwise, if MNOs compete on investments and roaming quality, they are not able to capture the entire gain of their investment as part of the gain is captured by the rival. This leads to the incentive to set a lower roaming quality. Now, if a regulatory authority wishes to enhance both investments and the quality of spillovers it might face a dilemma. As previously shown, competing MNOs increase investment levels for a roaming charge below cost (if spillovers are not too large), although in this case they set a lower roaming quality. Otherwise, for roaming charges above costs they set a better roaming quality, but set lower investment levels.

Proposition 3. *If MNOs jointly set investment levels and the roaming quality, investment levels are increasing in the roaming quality and MNOs always choose the maximal roaming quality, independent of the regulatory regime. If MNOs compete on investment levels and the roaming quality investment levels are decreasing in the quality of roaming for a roaming charge at or below costs, whereas investments may increase for a sufficiently high markup. MNOs choose a higher roaming quality, the higher the regulated roaming charge.*

6.2 Coverage competition

The base model above treated MNOs' coverage as symmetrically given. This section analyzes the effect of an increase in coverage locally around symmetric coverage. The decision takes place after the regulation policy (a) is announced but before MNOs set infrastructure levels. For ease of exposition of analytical expressions the roaming quality parameter β is set to one henceforth.[20] Providers incur no cost of coverage. This (extreme) assumption allows to focus on providers' strategic reasons to provide coverage.

It turns out that providers' coverage decisions are qualitatively unaffected by whether they set infrastructure investments in the preceding stage competitively or jointly, hence the following analytical expressions refer to the case providers compete on infrastructure investments in the preceding stage. The expressions for the case of joint infrastructure investments are relegated to the appendix.

Starting from symmetric coverage a provider's profit derivative with respect to its coverage is denoted as

$$\frac{\partial \Pi_i}{\partial \alpha_i}|_{\alpha_j=\alpha_i} = \frac{a-c}{(9\delta-4)^2}\Delta, \tag{23}$$

with

$$\Delta = \delta^2 \left(36(v-c) - (1-\alpha_i)63(a-c)\right) - \delta \left(26(v-c) - (1-\alpha_i)59(a-c)\right) \\ +4(v-c) - (1-\alpha_i)14(a-c).$$

Directly observe that for cost based regulation of $a = c$ every symmetric

[20]The analysis has been repeated for various parameters of β and led to similar results.

coverage is a Nash equilibrium. This is in line with Fabrizi and Wertlen (2008) who find that in the absence of sharing agreements any combination of coverage leading to full coverage in a Nash equilibrium.

For below cost regulation of $a < c$ it follows that $\Delta > 0$[21] and thus, $\frac{\partial \Pi_i}{\partial \alpha_i}|_{\alpha_j=\alpha_i} < 0$. For a below cost regulation a MNO's profit is locally decreasing in its coverage, hence it will not engage in expanding its coverage but rather shut down infrastructure if feasible. This would induce more fellow subscribers to roam on the rival's network and so the respective provider would save its operation cost c and only pays a roaming charge of $a < c$. Fabrizi and Wertlen (2008) also find that providers will not engage in expanding in overlapping territories. In their model, however, the result is due to maximization of roaming rents due to a negotiated above cost roaming charge, whereas in the present model the motivation relies on a cost saving argument due to a below cost charge.

For above cost regulation providers (locally) either have an incentive to expand or lower their served territory, since $\frac{\partial \Pi_i}{\partial \alpha_i}|_{\alpha_j=\alpha_i} \lesseqgtr 0$. The intuition is as follows. According to Eq. (5) the retail price is increasing in a, hence, providers have an incentive to expand coverage in order to enhance retail profit. However, if both providers expand coverage, entire roaming in the market decreases and providers are less able to benefit from an above cost charge per subscriber if fewer subscribers roam. A coverage expansion would be to the benefit of consumers, since it causes retail prices to decrease, that is, technically, $\frac{\partial p_i}{\partial \alpha_i} = \frac{(a-c)(1-3\delta)}{9\delta-4} < 0$. With fewer roaming in the market, the raise-each-other's cost effect of roaming charges plays less of a role.

If the roaming charge is only slightly set above costs the effect in the retail market dominates and providers have an incentive to increase coverage, otherwise, for higher charges providers benefit from roaming income per subscriber and have an incentive to set the lowest possible coverage to benefit from the roaming rents. Take for example parameter values of $v = 3, c = 2, \delta = 3$, and $\alpha_i = 0.7$. As long as the markup on costs is less than approx. 3 % providers locally increase coverage, otherwise they locally decrease coverage.

[21] Following assumption 1 it holds that $\delta > 2$ for $\beta = 1$.

7 Conclusion

Due to the widespread use of smartphones in recent years, MNOs have to discover new infrastructure models to meet the demand for third generation (3G) and to rollout 4G networks. Likewise the transition from 2G to 3G also in an early stage of the rollout of 4G providers tend to engage in network sharing and collaborations on infrastructure investments. From a competition policy perspective it is a relevant policy question whether MNOs should be allowed to collaborate in the investment stage and if and how to regulate network sharing. The results of the paper imply that MNOs' incentives to invest depend on: i) the regime of roaming charge regulation, ii) on the choice whether to allow MNOs to collaborate on investment levels, and iii) on the extent of the investment spillover. Providers prefer an above cost roaming charge, whereas a social planner prefers a below cost charge, which however, might both lead to over- and underinvestments from a social point of view.

The paper provides two extensions to the base model where providers are free to determine the roaming quality and their coverage. MNOs will choose maximal roaming quality whenever they are free to collaborate on investments and quality. However, if MNOs compete on investments and the roaming quality, the social planner might face a dilemma. For below cost charges MNOs increase investment levels but decrease the roaming quality, whereas for above cost charges they decrease investment levels but increase the roaming quality. The effect of roaming charges on coverage turns out to be ambiguous and depends on the relative magnitude in the retail and the roaming market.

The model is very stylized and is one attempt to capture the impact of roaming charges on strategic interactions among competing providers. It is able to show that the level of roaming charges might quite diversely affect MNOs' choices on investments, quality, and coverage. Although, there is clearly room for further developing and putting more structure to the model. One extension is to model non-linear prices such as two-part tariffs. Subscribers in different countries considerably vary in adopting pre- and post-paid tariffs. In 2010, 87 % of mobile contracts for over 25 year old customers in China were estimated to be pre-paid, in Italy two third, and in the UK roughly one half. Contrary, in Spain and the US roughly 80 % were post-paid. With two-part tariffs providers have two instruments to capture consumer surplus, an increase in per-minute prices will be accordingly adjusted by a reduction in the fixed fee since for higher per-minute prices firms are more willing to compete for subscribers. Hence, the standard voice communications literature shows that access charges have a neutral effect on profits which reduces regulatory concerns of high access charges. Access charges, however, have a non-neutral effect on investment levels. The paper has shown that both high and low charges may foster investments and hence consumers surplus. Thus, likewise the model of Valletti and Cambini (2005) access charges will have a non-neutral effect on profits. In their model above-cost charge have an investment-reduction effect. This may not necessarily hold true in the present setup and will depend on the extent of the investment spillover and the choice of whether to compete or to collaborate on investments.

Appendix

Proof of Proposition 1:
Consider MNOs jointly set investment levels at stage 2. Then they negotiate an access markup of

$$\widehat{a} - c = \frac{\delta(v-c)}{(1+\alpha)(4\delta - (1+\beta)^2)}.$$

It follows that $\hat{a} > c$ for $v > c$ and $\delta > \frac{1}{4}(1+\beta)^2$, which holds given the restriction on δ.
Consider MNOs compete on investment levels. They negotiate an access markup of

$$\widehat{a} - c = \frac{\delta(v-c)(9\delta + 10 + 34\beta^2 - 46\beta)}{36\delta^2 - (130\beta - 64\beta^2 - 31)\delta - 10 - 16\beta^4 + 4\beta^3 + 30\beta^2 + 8\beta}.$$

It follows that $\hat{a} > c$ for $v > c$ and $\delta > \frac{2}{9}(23\beta - 17\beta^2 - 5)$, which also holds given the restriction on δ.

Coverage competition

Consider providers set infrastructure investments jointly. It follows that

$$\frac{\partial \Pi_i}{\partial \alpha_i}|_{\alpha_j=\alpha_i} = \frac{a-c}{9\delta-8}\Theta,$$

where

$$\Theta = \delta\left(4(v-c) - (1-\alpha_i)7(a-c)\right) + 8(1-\alpha_i)(a-c).$$

Hence, qualitatively the results remain unchanged compared to the case providers compete on infrastructure in the preceding stage. For cost based regulation every symmetric coverage is a Nash equilibrium. For below cost regulation it follows that $\frac{\partial \Pi_i}{\partial \alpha_i}|_{\alpha_j=\alpha_i} < 0$ since $\Theta > 0$. For above cost regulation providers have both an incentive to expand or lower coverage.

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