Demand-side Spillovers and Semi-collusion in the Mobile Communications Market[#]

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Abstract: We analyze roaming policy in the market for mobile telecommunications. Firms undertake investments in network infrastructure to increase geographical coverage, capacity in a given area, or functionality. Prior to investments, roaming policy is determined. We show that under collusion at the investment stage, firms' and a benevolent welfare maximizing regulator's interests coincide, and no regulatory intervention is needed. When investments are undertaken non-cooperatively, firms' and the regulator's interests do not coincide. Contrary to what seems to be the regulator's concern, firms would decide on a higher roaming quality than the regulator. The effects of allowing a virtual operator to enter are also examined. Furthermore, we discuss some implications for competition policy with regard to network infrastructure investment.

Keywords: Mobile communications, roaming, competition, virtual operators

JEL classification: L13, L51, L96

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1 Introduction

We analyze competing mobile telephony providers' incentives to invest in, and share infrastructure. Furthermore, we analyze whether the regulator should intervene into the firms sharing agreements, and whether the regulator should allow the firms to coordinate their investments. The infrastructure investment we have in mind is upgrading of the mobile networks from second generation (2G) to third generation (3G) systems. Agreements on sharing infrastructure are called roaming in mobile markets.

The main improvement of 3G networks (e.g. UMTS) compared to the current 2G mobile networks (e.g. GSM) is to increase the speed of communication in the access network and thereby give access to new services and new functionality for existing services. Investments will consequently increase consumers' willingness to pay for mobile access. The basic mechanism driving our results is that investments carried out by one firm increase the value of the service provided by other firms when there is a roaming agreement between the firms.

An analysis of consequences of coordinating investments and infrastructure sharing seems to be more relevant in 3G as compared to 2G networks. First, while the providers of 2G networks (GSM) made their investment non-cooperatively, we now see that several providers of UMTS are coordinating their investments in infrastructure (e.g. in Sweden and Germany). There has been a heated debate whether the regulator should allow the firms to cooperate at the investment stage. Second, the benefit from sharing agreements through roaming seems to be higher in 3G than 2G networks. In current 2G networks the consumers have access to a given capacity (9.6 kbit/s), while in 3G the available capacity for data transmission may be allocated in a more dynamic way. If there are free resources in the network, a consumer may be given a capacity of up to 2 megabit/s. However, as the number of users in a given area at a given time increases, each user will have less capacity available. This may increase the value of infrastructure sharing agreements. There are in general potential gains from sharing network capacity when the load in two networks is not perfectly correlated. Let us illustrate this by a simple example. At a given time, operator *A* has no free capacity in its network whereas operator *B* has idle capacity. Suppose now that a subscriber of *A* tries to download a huge amount of content and needs 2 megabit/s. If there is no capacity sharing agreement between *A* and *B*, the customer will not be able to access such services at that time. However, if a sharing agreement is established between the operators, the service will be available to the consumer. In this situation, it is obvious that an investment in capacity by B will increase the willingness to pay for subscriptions from firm A.

We analyze a stylized multi-stage model where the firms first agree on roaming quality, second choose their investment non-cooperatively or cooperatively, and finally compete à la Cournot. We investigate whether it is welfare improving to let the firms semi-collude by choosing their investment cooperatively before they compete in the downstream market. Alternatively we may have semi-collusion where the firms compete at the investment stage and collude in the retail market such as in Brod and Shiwakumar (1999), Fershtman and Gandal (1994), and Steen and Sørgard (1999). More generally the latter form of semi-collusion seems realistic since the firms typically will collude on the most observable variable. Usually this will be the price in the retail market. However, our motivation is that we observe collusion at the investment stage in the market we consider, and the effects of allowing such collusion are what we want to investigate. Therefore, we do not consider collusion in the final product market.[1]

In our basic model we assume that there are two symmetric facility-based firms. If the investments are set non-cooperatively we show that voluntary roaming leads the firms to agree on a too high roaming quality compared to the social optimum. Moreover, the investments are strategic complements, and firms will then invest less with voluntary than mandatory roaming. In contrast, if the investments are set cooperatively, the firms' choices on the roaming quality coincide with the regulator's interests. We show that the firms should be allowed to semi-collude in the way described above, since this yields the highest welfare.

In an extension of the basic model we assume that there is a non-facility-based firm, or a virtual operator, in addition to the two facility-based firms. Whether the virtual operator should be allowed to enter the market and to which extent the presence of such an operator will affect the incentives to invest in infrastructure has been a hot topic in the industry and amongst regulators. This debate started when the Scandinavian virtual mobile operator Sense Communication attempted to get access to the facility-based mobile operators' networks. The

[1] See Busse (2000) and Parker and Röller (1997) for analysis of tacit collusion in the mobile market.

facility-based firms were reluctant to grant Sense Communication access.[2] A much more friendly reception was given to Virgin Mobile in the UK.

The roaming quality between the entrant and the two-facility-based firms in our model is assumed to be weakly lower than the roaming quality between the two facility-based firms. We show that when the investments are set non-cooperatively between the facility-based firms an increase in the roaming quality of the incumbents may now increase the investments. This is in contrast to the basic model.

We analyze a type of semi-collusion where the firms may collude at the investment stage and compete in the retail market. Our model is an extension of the multiple stage models of d'Aspremont and Jacquemin (1988) and Kamien *et al.* (1992) considering R&D investment. Through the roaming agreements the investments in infrastructure give rise to spillover effects similar to those considered in models of strategic R&D investments. In the majority of these models, the externality is exogenous. In our model, we focus on the situation where the level of the externality is endogenously determined.[3] Furthermore, in contrast to the majority of the R&D literature we introduce asymmetry between the firms. That is, there are firms that invest in infrastructure and firms that do not invest.[4]

We also make some other key assumptions in our model. First, for the sake of simplicity we ignore the issue of interconnection (agreements that give access to rivals' customer bases) and focus on roaming only. We give roaming a wider interpretation than pure geographical coverage. Roaming agreements extend availability, such that (i) subscribers can make and receive calls via the infrastructure coverage of a rival operator, (ii) when there is congestion a customer may take advantage of the infrastructure of the rival, and (iii) give access to new functionality/services in the rivals' network.

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[2] Sense wanted to issue their own SIM cards, but the Scandinavian facility-based operators refused this. Sense filed a complaint to all national regulators, but only the Norwegian regulator supported it. Telenor's appeal to the Norwegian regulator was still pending when Sense filed for bankruptcy in March 1999 (Matthews, 2000). Now, Sense Communication, along with several other virtual operators, has an agreement with Telenor to resell airtime.

[3] Katsoulacos and Ulph (1998a,b) introduce endogenous levels of spillovers between firms. Contrary to their models we assume that the investments undertaken by firms result in product innovation with probability one. Furthermore, our focus is on a context where firms (or a regulator), in the terminology of Katsoulacos and Ulph, choose the degree of information sharing and not research design. We are accordingly examining investments with firms operating in the same industry, but pursue complementary research.

[4] See e.g. De Bondt (1997) for a survey of the R&D literature of strategic investments.

Second, to simplify we make the assumption that there is no side payments between firms engaged in roaming. If firms have the ability to write complete contracts in all dimensions of the infrastructure sharing (roaming), all external effects from the investment can in principle be internalized through the price mechanism. Then, the problem of spillovers through roaming analyzed in this paper may vanish. Since sharing agreements in the next generation systems should ensure a dynamic capacity allocation, it is however rarely possible to write complete contracts in all dimensions. Thus, even if a price mechanism for roaming is implemented, it will not be able to internalize all external effects. This is similar to what we see in the Internet, where infrastructure sharing of backbones is common (Crémer, Rey and Tirole, 2000). Note that regulation may also constrain the firms' ability to internalize external effects through pricing. In particular, this will be important in the interaction between the facility-based firms and the non-facility based firm (virtual operators).

Third, we make the simplifying assumption that consumers only pay for subscription, not for usage. On the one hand this is evidently a restricting assumption since mobile providers typically employ various types of nonlinear pricing. On the other hand, it is far from evident what the alternative is, and in particular, whether mobile providers will choose to price discriminate between calls originated off-net and calls originated on-net.[5] The focus in our model is however on how availability in various dimensions (capacity, speed etc.) affects the choice of supplier. Consequently, our focus is on demand for subscriptions, not usage and then it is sufficient to consider pricing as a fixed per period fee.

Fourth, we assume Cournot competition in the retail market. We interpret the quantity firms dump in the retail market as the number of subscriptions they sell. A justification for assuming Cournot competition is that, due to the fact that the amount of radio spectrum available is scarce, there are both physical and technological limits to capacity. Furthermore, the firms must choose a capacity level which is built (or rented) in both the backbone network and the access network (number of base stations) *prior* to the competition in the retail

[5] In addition to the pricing issues, by introducing a call volume dimension we will have to model the cost structure for calls originating and terminating on the same net by a subscriber of that network. Under such a generalization of our model it would also be natural to relax assumption 2 and introduce a volume price on roaming (as well as a volume price on interconnection). A proper modeling of all these pricing and cost components will lead to a very complex model. By disregarding both the revenue and the cost side of traffic we also avoid the so-called “bill and keep fallacy”.

market.[6] This will be more important with 3G systems where the capacity needed increases. However, as shown by Kreps and Scheinkman (1983), strong assumptions are required to ensure that a capacity constrained price game result in identical results as a Cournot game. Nevertheless, this seems more appropriate than assuming a Bertrand game without capacity limits.

The rest of the paper is organized as follows: In section 2, the model with only facility-based firms is presented and analyzed. In section 3, we provide an extension to the basic model by introducing a virtual operator. In section 4, some concluding remarks are made.

2 The model

In our basic model we will look into a duopoly case where we assume the following three-stage game:

Stage 1: Either the firms or the regulator determines roaming quality

Stage 2: The firms determine infrastructure investments either non-cooperatively or cooperatively

Stage 3: Cournot competition

There are four different variants of the game depending on the stage 1 and stage 2 strategies:

		Stage 2: Investments	
		Competitive	Collusive
Stage 1: Roaming	Voluntary	**Game 1**	**Game 3**
	Mandatory	**Game 2**	**Game 4**

Figure 1 The four variants of the game

[6] The basic structure in a mobile network is that coverage in a given area is achieved through a number of base stations covering given areas (cells). Hence, a mobile network consists of a net of such cells. The spectrum band allocated for mobile use limits the total bandwith a cell can handle at a given point of time. Thus total capacity measured is limited and one bandwith hungry user occupying 2 Mbit/s is crowding out approximately 200 ordinary voice calls. In situations with capacity problems it is possible to invest in higher capacity through what is called cell splitting. Cell splitting implies that a given area is served with a higher number of smaller cells.

The choice of whether firms cooperate when determining their investment levels will depend on whether such cooperation is approved by the competition authorities. Regarding stage 2 and 3 the structure in our model is fairly similar to Kamien *et al.* (1992) and d'Aspremont and Jacquemin (1988). The generic feature of the investment is that it leads to product innovation increasing the quality of the service.

One interpretation of the timing in our model is that roaming policy may be part of the licenses to the operators in the case where the degree of roaming is mandatory, and therefore chosen *prior* to investments taking place. When roaming is voluntary, we assume that firms can commit to a policy on roaming *prior* to undertaking the investments. Indeed, the timing of the roaming quality decision relative to infrastructure investments can obviously be different. To be more specific, the infrastructure investment may be decided *prior* to a decision on roaming quality. Such timing may involve problems with investment hold-ups, but this will not be our main focus. Thus, in our choice of timing we implicitly assume that the firms/the regulator can credibly commit to a given policy on roaming. As far as the regulator is concerned, the issued licenses may serve as a commitment device, whereas the commitment problem under voluntary roaming is solved, e.g. if a given roaming policy is embedded in the network design (e.g. type of interfaces).[7]

2.1 The demand side

When firm *i* invests in its infrastructure it impacts on the quality of the services its own customers are offered, but there may also be an impact on the quality of the services offered by the rival firm *j*, and vice versa. Given a roaming policy β and investment decisions x_i, we can now write the total quality offered to consumers by firm *i*:

$$a_i = a + x_i + \beta x_j \qquad (1)$$

where x_i is network investment undertaken by firm *i,* and x_j indicates the investment by the rival. We assume that $\beta \quad [0,1]$ is a parameter indicating the degree of roaming. This

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[7] Poyago-Theotoky (1999) considers a model of R&D where the degree of spillover is endogenous. In her model, the timing of the game is different from ours, in that the R&D investment decision (which is equivalent to our infrastructure investment decision) is made *prior* to the decision on how much information to share with competitors. In addition, she allows firms to choose different levels of spillover. In our model, the degree of spillover (interpreted as roaming quality) is reciprocal, in that the degree of spillover is identical in both directions. When firms choose R&D cooperatively they choose to fully disclose their findings, whereas when there is competition in R&D firms choose minimal disclosure. The latter result is very different from what we find in our model.

parameter measures the externality effect from sharing infrastructure. If β = 1, there is an agreement on full roaming, while β = 0 implies minimum roaming quality.

The inverse demand function faced by firm *i*:

$$p_i = a_i - q_i - q_j$$

The price, p_i, is the subscription fee for availability (i.e., a monthly fee). The externality introduced above is such that when firm *i* invests in infrastructure, the marginal willingness to pay for the final products produced by both firms is increasing.

2.2 The supply side

We assume a linear cost function in the final stage for firm *i*, given by $C_i = cq_i$. The cost *c* is the direct cost associated with access connection of one user. We assume that firms face quadratic (network infrastructure) investment costs, given by $TC_i(x_i) = \varphi x_i^2 / 2$, where φ > 4/3. We will later demonstrate that the restriction on φ ensures a unique and stable equilibrium. Overall profit for firm *i* is then:

$$\pi_i = (p_i - c)q_i - \varphi x_i^2 / 2 \tag{2}$$

2.3 Welfare

We assume that the regulator maximizes welfare given by the sum of producer and consumer surplus:

$$W = CS + \pi_1 + \pi_2 \tag{3}$$

Since firms are symmetric and the inverse demand functions are linear with identical slopes, we can write consumer surplus as $CS = 2q^2$, where *q* is the symmetric production level of each firm.

2.4 Cournot-competition (stage 3)

At stage 3, firm *i* maximizes the profit function: $\pi_i = (p_i - c_i)q_i$. Combining the first order conditions for the two firms we obtain equilibrium quantities:

$$q^*_i = \frac{a - c + x_i(2-\beta) + x_j(2\beta - 1)}{3}$$

Note that in a symmetric equilibrium ($a_i = a_j$), the equilibrium quantity is given by $q^* = (a_i - c)/3$.[8] This quantity is monotonously increasing in $a_i = a_j$, and this implies that consumer surplus is monotonously increasing in a_i. Firm i obtains stage 3 equilibrium profits given by $\pi_i = (q^*{}_i)^2$.

2.5 Infrastructure investment (stage 2)

When firms invest in infrastructure at stage 2 of the game, they take into account the effect such investments has on the stage 3 equilibrium.

2.5.1 Non-cooperative solution

At stage 2, the firms maximize the profit function (2), subject to Cournot equilibrium quantities at stage 3, which implies that the (symmetric) equilibrium investment is given by:

$$x_{nc}^* = \frac{(4-2\beta)(a-c)}{9\varphi - 2(2-\beta)(1+\beta)} \tag{4}$$

In equilibrium, firms' profits are non-negative for all permissible parameter values, and consequently firms will participate in the game. Furthermore, the symmetric equilibrium is the unique equilibrium.[9] Our result is analogous to d'Aspremont and Jacquemin (1988) and Kamien *et al.* (1992), and is summarized in the following lemma:

Lemma 1 *If* $\beta > 1/2$*, then* x_i *and* x_j *are strategic complements; that is,* $(\partial x_i / \partial x_j)^{nc} > 0$. *Reversing the inequality makes* x_i *and* x_j *strategic substitutes.*

When one firm invests in its infrastructure, the equilibrium quantity of the other firm may or may not increase as a result of the spillover through the roaming agreement. As pointed out by Kamien *et al.* (1992), the spillover externality (or investment externality) is positive if and only if $\beta > 1/2$. In other words, the spillover externality is positive only when x_i and x_j are strategic complements.

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[8] As it turns out, the unique equilibrium in investment is indeed the symmetric equilibrium.

[9] The second-order condition requires that $2(2-\beta)^2 - 9\varphi < 0$. In order to have a stable equilibrium the slope of the reaction function has to have an absolute value below unity. It is straightforward to demonstrate that this condition is fulfilled for φ > 4/3. Hence, the second order condition is also fulfilled when we have assumed that φ >4/3. Finally, it can be shown that the symmetric equilibrium is indeed unique.

2.5.2 Cooperative solution

In the cooperative case the two firms coordinate their infrastructure investments at stage 2, and compete à la Cournot at stage 3 in the same way as above. When determining the profit-maximizing choice of investments at stage 2, firm *i* maximizes the joint profit of the two firms (i.e. industry profits):

$$\max_{x_i} \ \Pi = (q_i)^2 + (q_j)^2 - \frac{\varphi}{2}(x_i^2 + x_j^2) \quad \text{for } i \neq j$$

The following first-order condition yields the equilibrium investment for a given firm under collusion:[10]

$$x_c^* = \frac{2(a-c)(1+\beta)}{9\varphi - 2(1+\beta)^2} \tag{5}$$

The cooperative solution yields lower infrastructure investment than the non-cooperative, $x_c^* < x_{nc}^*$, if and only if $\beta < 1/2$. This is equivalent to the results obtained by d'Aspremont and Jacquemin (1988) and Kamien *et al*. (1992).

Observe furthermore that for $\beta < 1/2$, equilibrium quantity in the final stage of the game is lower under collusion relative to the non-cooperative case. Consequently, consumer surplus is, on the one hand, lower under collusion relative to non-cooperation if the roaming quality is sufficiently low. If, on the other hand, $\beta > 1/2$, consumers' surplus is higher under collusion at the investment stage. In addition, firms' profits under collusion are always at least as large as under non-cooperation. For $\beta = 1/2$ firms are indifferent between collusion and non-cooperation at stage 2. Consequently, a welfare-maximizing regulator would, provided that the roaming quality is sufficiently high (i.e. $\beta > 1/2$), choose to allow collusion at stage 2 and such collusion would be in the firms' interests. In the next section we examine which level of roaming quality a welfare-maximizing regulator would choose.

2.6 Roaming quality (stage 1)

In this section, we extend the model by considering the two cases where: 1) Firms decide roaming quality (*voluntary roaming*) and 2) the regulator decides roaming quality (*mandatory*

[10] In the same way as in game 1, the second-order condition, $2(1+\beta)^2 - 9\varphi < 0$, is satisfied with our parameter restrictions.

roaming). These two cases combined with the two ways of determining investments at stage 2 yields four different games (see Figure 1). The analysis in this section can be seen as an extension to the basic model with exogenous R&D spillovers to examine endogenous spillovers.

2.6.1 Game 1, voluntary roaming when investments are determined non-cooperatively

Recall that equilibrium infrastructure investment (under non-cooperation) is given by equation (4). Direct differentiation of (4) yields the following result:

Lemma 2 *When firms determine the investments non-cooperatively, the infrastructure investment decreases as the roaming quality increases since* $\partial x_{nc}^{*} / \partial \beta < 0$.

The intuition behind Lemma 2 is as follows: We are considering the equilibrium with *reciprocal* spillover levels, implying that both firms' final products increase in value to consumers by the same proportion (contrary to what is the case in section 3). Hence, there is no product differentiation gain from investments for any of the firms. When firms do not cooperate at the investment stage, they do not internalize the effect of the investment on the other firm's profit. An increase in the degree of roaming quality is thus affecting the marginal revenue from investing in infrastructure adversely, due to the fact that the investing firm is unable to capture the effect on the rival's profit. When examining the stage 3 equilibrium we observe that equilibrium quantities increase in both the degree of roaming quality and the investment level. Since quantities are strategic substitutes, the rival firm will increase its production if you reduce yours. Each firm will then have to be more cautious and ration its production of the final product more than is the case if they collude in the investment stage. To achieve a substantial enough reduction, any given firm will have to limit its production even more. Consequently, since q_i increases when β increases and $\left(q_i + q_j\right)$ increases when x_i increases, the investing firms can ration the final product market by reducing the level of investments when the degree of roaming quality increases.

The competitive equilibrium infrastructure investment is given by equation (4); $x_{nc}^{*} = x_{nc}(\beta)$. From Lemma 2 we know that $x_{nc}^{'}(\beta) < 0$. Using the symmetry of the problem the equilibrium profit is accordingly:

$$\pi = \left(\frac{a + (1+\beta) x_{nc}(\beta) - c}{3} \right)^2 - \varphi \frac{(x_{nc}(\beta))^2}{2} \tag{7}$$

By differentiating equilibrium profit with respect to β, we find the roaming quality preferred by the firms.

$$\frac{2}{9}\left(a-c+(1+\beta)x_{nc}(\beta)\right)\left(x_{nc}(\beta)+(1+\beta)x_{nc}^{'}(\beta)\right)-\varphi x_{nc}^{'}(\beta)=0 \tag{8}$$

It can be shown that the optimal β for the firms is independent of (a-c). The solution to equation (8) will be a function of the convexity of the investment cost function, i.e. of the value for φ. The profit maximizing choice with respect to β is increasing and concave in φ and strictly larger than 9/10. As an example; when $\varphi = 3/2$ the expression given by equation (8) is concave over the interval where it is defined and the first order condition is satisfied for $\beta = 0.941$. If the firms determine roaming quality, the firms will accordingly agree on $\beta = 0.941$ as the preferred level of roaming.

However, there may be a commitment problem for the firms. After firms have chosen their level of expenditure on network infrastructure (at stage 2), both firms have an incentive to renegotiate the roaming quality between stages 2 and 3. The reason for this is that for a given level of x_i, the (stage 3) Cournot-equilibrium profit of both firms is strictly increasing in β. If firms cannot commit to the roaming quality chosen at stage 1 of the game, we may thus experience hold-up problems in network infrastructure investments.[11] As indicated earlier, this commitment problem is solved if roaming policy is embedded in the network design, such that the firms cannot change roaming policy after the investments have been made. Furthermore, in section 3, we demonstrate briefly that the introduction of a virtual operator can eliminate the potential commitment problem for the firms.

2.6.2 Game 2, mandatory roaming when investments are determined non-cooperatively

In this section we investigate the roaming quality a welfare-maximizing regulator would choose, which can either be considered as a benchmark case or as the chosen roaming quality under *mandatory roaming*. We assume that the regulator maximizes the objective function given by equation (3). Producer surplus is calculated above (equation 7). Consider now the roaming quality preferred by consumers. We know that the equilibrium is symmetric in the

[11] Since the firms' profit is increasing in roaming quality for a given level of investment, firms have incentives to increase β to its maximum after the investments are sunk. The hold-up problem arises because we know that when investments are made non-cooperatively, the marginal revenue of the investments is reduced when β increases. Thus, if firms know that, ultimately, roaming quality is chosen to give perfect roaming, they will hold back on investments.

sense that the two firms invest in the same level of infrastructure and that they offer the same quantity at stage 3 of the game. Let x^* and q^* denote the profit-maximizing choices of investment and quantity, respectively. In the equilibrium, we have the following equilibrium price:

$$p = a + (1+\beta)x^* - 2q^*$$

Inserting for the non-cooperative equilibrium investment given by equation (4), and $q^* = ((a-c)+(1+\beta)x_{nc}{}^*)/3$ the consumer surplus becomes:

$$CS_{nc} = \frac{2\left[(a-c)+(1+\beta)x_{nc}(\beta)\right]^2}{9} \tag{9}$$

By differentiating consumer surplus given by equation (9) with respect to β, we find that the first order condition is satisfied for roaming quality $\beta = 0.5$.[12] Consequently, a roaming quality determined at $\beta = 0.5$ is the consumer surplus maximizing quality level.[13]

The roaming level maximizing consumer surplus can be compared to the roaming quality maximizing profits for the firms, (equation 8). In section 2.6.1 we demonstrated that the roaming level maximizing producer surplus is strictly larger than 9/10. It is accordingly evident that the firms prefer a roaming level exceeding the roaming level preferred by consumers. Since welfare is the sum of consumer and producer surplus, the welfare maximizing roaming level (game 2) is below the level preferred by the firms (game 1). This result is summarized in Proposition 1:

Proposition 1 *Assume that investments are undertaken non-cooperatively. Voluntary roaming induces firms to choose a higher level of roaming quality relative to the social optimum. Consequently, in a voluntary roaming regime firms invest less in network infrastructure than in a mandatory regime.*

The intuition behind this result is as follows: For a given quantity of the final product, the consumers benefit from high levels of infrastructure investments. Firms also benefit from high levels of investments, *ceteris paribus*. However, the investing firms cannot capture all of the benefits from the investments (due to the spillover externality through the roaming agreement) and, in addition, firms face convex costs of investing. Consequently, firms will

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[12] The solution that $\beta = 0.5$ maximizes consumers' surplus is also independent of the convexity of the investment cost function, i.e. of the value for φ.

[13] The second-order condition for CS is satisfied for all permissible values of β.

choose a lower level of investment compared to the level that maximizes consumers' surplus. Furthermore, from Lemma 2 we know that incentives to invest in infrastructure are worse the higher the degree of roaming quality. In a situation with high roaming quality, each of the investing firms will attempt to be a free rider on the other firm's investments. Consequently, the equilibrium investment level will be lower. On the other hand, a welfare-maximizing regulator will be able to internalize all the externalities of roaming. Thus, when roaming is voluntary firms choose a high level of roaming quality to reduce investment incentives. When roaming is mandatory, a lower level of roaming quality is chosen to induce higher levels of investment in network infrastructure.

If firms are not allowed to collude at the investment stage, regulatory intervention may be needed. In this case, firms would set a higher roaming quality than the socially optimal level. Consequently, firms would agree on more compatibility than what would be beneficial to consumers and society as a whole. For consumers, an increase in roaming quality has two potentially opposing effects. Increased roaming quality implies (under non-cooperation) that investment is reduced. This implies that the size of the market is reduced (the inverse demand function is shifted inwards). For a given quantity, this results in a reduction in the price charged to consumers. This has a positive impact on consumers' welfare. However, a reduction in infrastructure results in a reduction in quantities sold in the last stage of the game. This has a negative impact on consumers' welfare. The overall effect of increasing quality is positive for low levels of roaming quality, and negative for high levels. For a sufficiently high roaming quality, an increase in roaming quality reduces consumers' welfare. Firms, on the other hand, can by setting a high roaming quality restrict the size of the infrastructure investments. As a result, the output of the final product in stage 3 of the game is also restricted, with an increase in equilibrium price.

2.6.3 Game 3 and 4, voluntary and mandatory roaming when investments are determined cooperatively

Recall that the equilibrium investment as a function of roaming quality is given by equation (5). Direct differentiation yields the following result:

Lemma 3 *When firms collude at the investment stage, the infrastructure investment increases as the roaming quality increases since* $\partial x_c^* / \partial \beta > 0$.

Contrary to the case of non-cooperative investment, the incentives to invest are in fact higher when the roaming quality is high. In this case, firms achieve a better coordination due to the fact that the effect on the other firm's profits is internalized. Thus, all benefits from the investments are credited to the investing firm, which changes investment incentives qualitatively. There is no longer the problem that each of the investing firms will have incentives to free ride on the other firm's investments. If firms determine a high (low) level of roaming quality, each firm's investment presents a large (minor) positive external effect the firms jointly can internalize. By inserting for the collusive equilibrium investment, x_c^* (given by equation 5), and third stage equilibrium quantities, we obtain consumer surplus (under collusion), CS_c:

$$CS_c = 2\left(\frac{a-c}{3} + \frac{2(a-c)(1+\beta)^2}{3\left(9\varphi - 2(1+\beta)^2\right)}\right)^2 \tag{10}$$

When firms decide on infrastructure investments collusively, consumer surplus given by equation (10) is increasing and convex in roaming quality over the relevant interval for β. Consequently, the optimal β for consumers is equal to unity (or maximal roaming quality). Quantity is increasing in roaming quality both directly and through the effect of roaming quality on investment. Furthermore, consumer surplus is increasing in quantity. Thus, a higher roaming quality implies a higher level of consumers' surplus.

Firms maximize their equilibrium profit under collusion with respect to β, which results in:

$$\frac{\partial \pi}{\partial \beta} = 2q_c^*\left(\frac{x_c^*}{3} + \left(\frac{1+\beta}{3}\right)\frac{\partial x_c^*}{\partial \beta}\right) - \varphi x_c^* \frac{\partial x_c^*}{\partial \beta} \tag{11}$$

where q_c^* is the stage 3 equilibrium quantity for each firm if firms collude at the investment stage. In the collusion case, the profit function is increasing and convex in β over the interval [0,1]. This implies that the optimal roaming quality for firms corresponds to the maximal roaming quality. We summarize our findings in Proposition 2:

Proposition 2 *Assume that firms collude at stage 2. The (unregulated) profit maximizing choice of roaming quality is identical to the choice of a regulator maximizing welfare. Consequently, the level of investments in infrastructure is identical in both the voluntary and mandatory roaming regimes.*

Since firms' and consumers' interests coincide there is no reason for governmental intervention and there is no need for considering game 3 and 4 separately. As in the non-cooperative case, consumers benefit from high investments in infrastructure for a given production level. However, to achieve high levels of investments, consumers now choose a *high* level of roaming quality. The main reason for the difference in our result is that firms, when they are allowed to coordinate their investments, are able to capture all benefits from the investments. Because of this, firms' investment incentives are changed and they now seek high roaming quality to induce high levels of investments, whereas in the non-cooperative case they seek high roaming quality to induce low levels of investments.

2.7 Collusive and competitive investments compared

At stage 2 of the game the level of investment in the network infrastructure is determined. As already stated, firms can either compete (games 1 and 2) or they can collude when determining the investment level (games 3 and 4). We may think of the decision to allow firms to collude or not as a decision taken by the competition authorities *prior* to commencement of the 3-stage game we analyze above.

Assuming that roaming is voluntary we can compare equilibrium under collusive and competitive investments, respectively (i.e. we compare games 1 and 3), to determine whether the investing firms should be allowed to collude or not at the investment stage. Under voluntary roaming the firms set the β so as to maximize profits. Firms are evidently better off under collusion as compared to competitive investments.[14] Furthermore, it follows from the calculations above that equilibrium consumer surplus is higher under collusion (game 3 and 4) as compared to equilibrium consumer surplus under competitive investments and mandatory roaming (game 1).[15] The intuition behind this result is as follows: Consumers' surplus increases, both in roaming quality for given investments and in investment for a given roaming quality. Since we have demonstrated that roaming is at the highest possible level under collusive investments and that investments are higher under collusion provided that $\beta > 0.5$, consumer surplus will indeed be higher under collusion.

In the figure below we illustrate the welfare effects of chosen roaming policy for a regulator under the two investment regimes for the parameter values $a = 3$, $c = 1$, and $\varphi = 3/2 > 4/3$:

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[14] When firms collude they can always mimic the outcome under competition, if they choose to deviate from this outcome it is because they are better off.

[15] This result is derived by first observing that consumer surplus (CS) is higher in game 2 as compared to game 1. Then a sufficient condition for demonstrating that CS is higher in game 3 and 4 as compared to game 2 is to assume that the regulator in game 2 determine the roaming at the level maximizing CS ($\beta = 0.5$). Then we can compare CS under collusion, equation (10), for $\beta = 1$ and compare it CS under competitive investments, equation (9), for $\beta = 0.5$. Then we find that $CS_{game\ 3\ and\ 4} \geq CS_{game\ 2} \geq CS_{game\ 1}$.

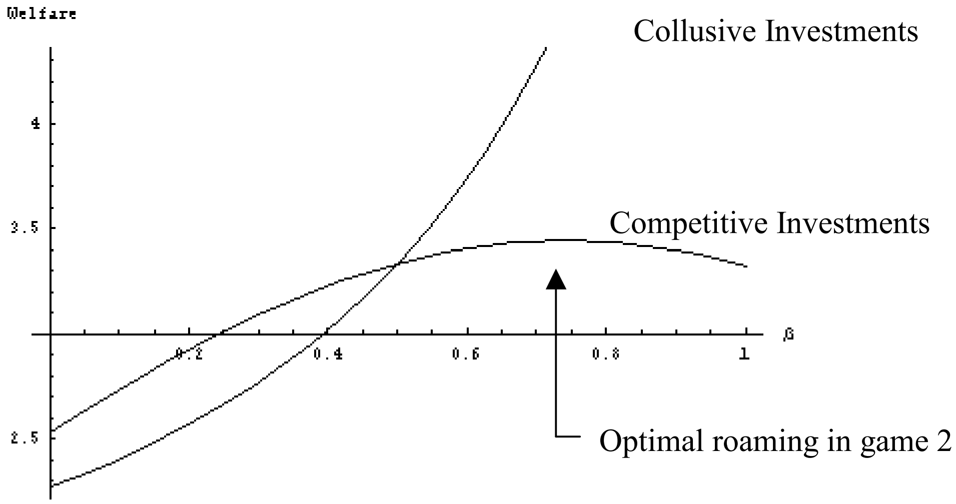

Figure 2 Welfare comparison of collusion versus non-cooperation

It is evident from the figure above that social welfare is maximized when the regulator allows firms to collude at stage 2, provided that the quality of roaming is sufficiently high (i.e. for β higher than 0.5). We know from the analysis above that a welfare maximizing regulator indeed will set the quality of roaming equal to unity when firms collude at the investment stage. The figure is also illustrating the, perhaps, counter intuitive results that it is detrimental to welfare to determine mandatory roaming at too high a level under competitive investments.

Consequently, the competition authorities (or a regulator) can never do worse than allowing collusion at the investment stage, provided that the firms/regulator can commit to a sufficiently high roaming quality. The reason is that allowing collusion allows the positive external effects to be internalized.

3 Entry of a non-facility-based firm

In this section we analyze a situation where there are two different types of firms. One type is *facility-based* and invests in its own infrastructure. We assume that there are two incumbents which both are facility-based as in the previous section. The other type is an entrant that is a *virtual operator*. The timing of the game is the same as in the above analysis, but it is of course only the facility-based firms which undertake investments at stage 2 and we assume that the facility-based firms have all the bargaining power in determining the quality of roaming for the virtual operator.

The model is amended to incorporate the fact that there are now two types of firms. In the case where the entrant is a virtual operator we have:

$$a_i = a + x_i + \beta^f x_j$$
$$a_v = a + \beta^v (x_i + x_j),$$

where subscript $i, j = 1,2,\ i \neq j$ represents the two incumbents, and subscript v represents the virtual operator.[16] The parameter β^f represents the degree of the roaming quality between the facility-based firms, while β^v is the roaming quality from a facility-based operator to a virtual operator. We restrict the analysis to the case where $\beta^f \geq \beta^v$.[17] The parameters β^v and β^f can also be interpreted as the virtual operator's and facility-based operator's capabilities of transforming the inputs into a final product of high quality, respectively.

The profit functions of the facilities firms are equal to equation (2), while the profit of the virtual operator is $\pi_v = (p_v - c)q_v$. By combining the stage 3 first order conditions for the three firms we obtain the following equilibrium quantities:

$$q_i^* = [(a-c) + x_i(3 - \beta^f - \beta^v) + x_j(3\beta^f - \beta^v - 1)]/4$$
$$q_v^* = [(a-c) + (x_i + x_j)(3\beta^v - \beta^f - 1)]/4$$

3.1 Incumbents set the investments non-cooperatively

When the two facility-based firms set their investment non-cooperatively, we use the symmetry between the two firms, and we find the equilibrium investment for each facility-based firm: [18]

$$x = \frac{(a-c)(3 - \beta^f - \beta^v)}{8\varphi - 2(3 - \beta^f - \beta^v)(1 + \beta^f - \beta^v)} \tag{12}$$

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[16] Ceccagnoli (1999) gives a similar formulation with process innovation. In contrast to us he only focuses on the case where the R&D-investment is set non-cooperatively.

[17] This seems to be an appropriate assumption if the virtual operator is simply a reseller of airtime (e.g. Sense Communication in Scandinavia). However, if the virtual operator has a well known brand name and possesses detailed knowledge about certain segments of the market (e.g. Virgin in the UK), it may be reasonable to assume that investments benefit the virtual operator more than they benefit the incumbents.

[18] The second order condition is fulfilled if $\varphi > 9/8$, which also ensures stability.

We now examine how the equilibrium investment level x changes when β^f and β^v change:

Proposition 3 *When introducing a virtual operator and the investments are made non-cooperatively by the facility-based firms, increased roaming quality between the investing firms may result in a higher equilibrium investment level; i.e.* $\partial x / \partial \beta^f > 0$ *if and only if* $\left(\beta^f + \beta^v\right) < 2\sqrt{\varphi} - 3$. *Furthermore, increased roaming quality to the virtual operator reduces investment incentives,* $\partial x / \partial \beta^v < 0$.

Proof:

$$\frac{\partial x}{\partial \beta^f} = \frac{-(a-c)[8\varphi - 2(3-\beta^f-\beta^v)^2]}{[8\varphi - 2(3-\beta^f-\beta^v)(1+\beta^f-\beta^v)]^2}$$

$$\frac{\partial x}{\partial \beta^v} = \frac{-(a-c)[8\varphi + 2(3-\beta^f-\beta^v)^2]}{[8\varphi - 2(3-\beta^f-\beta^v)(1+\beta^f-\beta^v)]^2} < 0$$

The first expression is positive if and only if $[8\varphi - 2(3-\beta^f-\beta^v)^2] < 0$. This implies that $\beta^f + \beta^v < -3 \pm 2\sqrt{\varphi}$. Since $\beta^f + \beta^v \quad [0,2]$ the only root possibly satisfying the inequality is $\left(\beta^f + \beta^v\right) < 2\sqrt{\varphi} - 3$ .QED.

Recall the basic model with only two facility-based firms. Then, if investments were undertaken non-cooperatively, the incentives to invest were lower the higher the degree of roaming quality was. For sufficiently high values of the roaming qualities we obtain a similar result in the presence of a virtual operator. We observe from Proposition 3 that, contrary to the basic model, the incentives to invest may in fact be improved the higher the roaming quality is between the facility-based firms. This will be the case given a combination of a small sum of $(\beta^f + \beta^v)$ and sufficiently large φ.

In stage 1 of the game, either the investing firms or the regulator choose the level of roaming quality. Our findings suggest that if roaming is *voluntary* and investments are made non-cooperatively, the investing firms will choose to set the roaming quality between the investing firms as high as possible ($\beta^f = 1$). The roaming quality between an investing firm and the virtual operator is set as low as possible ($\beta^v = 0$).

It may however be the case that profit for the virtual operator is negative in this solution. A sufficient condition for ensuring non-negative profits for the virtual operator is that the convexity of the investment cost function is sufficiently large (i.e. for φ sufficiently large). It can be shown that φ > 2 ensures non-negative profits for the virtual operator under competitive investments. The intuition behind this result is that when $(3\beta^v - \beta^f - 1) < 0$ any investments in infrastructure undertaken by the facility-based firms will reduce the equilibrium output of the virtual operator, and consequently, infrastructure investments may be used to deter entry. If, however, the cost of investing is sufficiently convex, then the equilibrium level of investment is low enough not to deter entry by the virtual operator.

We only consider the case where the facility-based firms choose accommodation of entry by the virtual operator. In order to ensure this we assume that the costs are sufficiently convex (high value of φ). As long as we have accommodation of entry proposition 3 holds. However, for lower values of φ, it may be optimal for the facility-based firms to invest such that the virtual operator is foreclosed from the market. In this case, the higher the β^v compared to β^f, the more the facility-based firms have to invest in order to deter entry.[19]

When roaming is *mandatory*, a welfare-maximizing regulator decides the appropriate levels. The regulator will choose a roaming policy that corresponds to the voluntary roaming case. This seems to correspond well to intuition. By keeping β^v low and β^f high, firms have better incentives to invest in infrastructure. Furthermore, a higher level of investment leads to more output being produced in the final product market, which is a direct benefit to consumers. Consequently, there is little scope for regulatory intervention in this case. The main result in this section then suggests that the provision of the right investment incentives is of greater importance than allowing the virtual operator entry at equal terms to the incumbents.

3.2 Incumbents set the investments cooperatively

When the facility-based firms set investments cooperatively they maximize the joint profit, and by inserting for optimal stage 3 quantity we obtain the following equilibrium investment level: [20]

$$x = \frac{(a-c)(1+\beta^f - \beta^v)}{4\varphi - 2(1+\beta^f - \beta^v)^2} \tag{13}$$

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[19] In a similar context, the case where a facility-based firm over-invests to deter entry is analyzed by Foros (2000).

[20] Note that for the equilibrium investment level to be positive, the investment cost needs to be sufficiently convex; this requires $\varphi > 2$.

Hence we have the following results:

Proposition 4 *When facility-based firms invest in infrastructure cooperatively, the investment level is unambiguously increasing in the degree of roaming quality between the cooperating firms,* $\partial x / \partial \beta^f > 0$, *and decreasing in the roaming quality between facility-based firm and the virtual operator,* $\partial x / \partial \beta^v < 0$.

The proof is straightforward and hence omitted.

Similar to our findings when investment is undertaken non-cooperatively, we observe that the equilibrium investment level is reduced whenever the roaming quality between the investing firms and the virtual operator increases. The intuition is the same as in the non-cooperative case. One important reason for investing in infrastructure is to differentiate its product from that of the competitor. If the roaming quality between the investing firms and the virtual operator is sufficiently high, the importance of the differentiation effect diminishes. As mentioned above, the degree of roaming quality may be interpreted either as the quality of the access provided to the virtual operator or as the virtual operator's capability of transforming the product innovation resulting from the investment made by the facility-based firms into high quality final products. Consequently, our findings suggest that any increase in the quality of input or in the virtual operator's capabilities reduces the facility-based firms' incentives to invest in infrastructure.

Our results for both voluntary and mandatory roaming when investments are undertaken cooperatively suggest that there is little scope for regulation. This is also the case when investments are undertaken non-cooperatively. Both the investing firms' interests and the interests of a welfare-maximizing regulator coincide. When the facility-based firms cooperate at the investment stage, they maximize joint profit with respect to (β^f, β^v), whereas a welfare maximizing regulator chooses (β^f, β^v) to maximize the sum of profits and consumers' surplus. The solution in both cases yields maximum roaming quality between the facility-based firms and minimal roaming quality between facility-based firms and the virtual operator. In order to ensure nonnegative profits for the virtual operator when $\beta^v = 0$ we must however make further restrictions on the convexity of the investment cost function. A sufficient condition is that $\varphi > 4$.

For a given investment level, an increase in the degree of roaming quality to the virtual operator is a social benefit and adds to consumers' surplus. However, increasing the roaming quality to the virtual operator adversely affects the facility-based firms' incentives to invest in infrastructure, and higher levels of investments is also a benefit to consumers. When a virtual operator is allowed to enter and investments are undertaken collusively the trade-off is the same as when investments are undertaken non-cooperatively, and the investment incentives dominate.

3.3 Some remarks on entry of a virtual operator

One remaining question is whether the competition authorities (or a regulator) should allow a virtual operator to enter or not. It is reasonable to assume that such entry should be encouraged if the entry implies that welfare is higher than is the case in the absence of a virtual operator. We assume that the decisions to allow entry by a virtual operator and whether to allow collusion are taken *prior* to commencement of the three-stage game analyzed above. Without going into details, it can be shown that welfare is higher if collusion at the investment stage is allowed (as is also the case without a virtual operator), and the reason is again that the positive externality can be internalized more easily under collusion.

Furthermore, it can also be shown that welfare is indeed higher when entry of a virtual operator is allowed when collusion is allowed. Since we know that welfare under collusion is higher than in the non-cooperative case, we need to show that welfare under collusive investments *with* a virtual operator is higher than without the virtual operator. Then, we have essentially proven that the subgame-perfect equilibrium policy for the government is to allow entry by a virtual operator and allow facility-based firms to cooperate at the investment stage.[21] Furthermore, we have seen that the optimal roaming policy implies that the virtual operator is only given minimal roaming quality, which means that the entry for the virtual operator is not on particularly generous terms.

A final point to be made is that the introduction of a virtual operator can eliminate the commitment problem for firms. Note that firms choose the roaming quality *prior* to undertaking investments, and in the absence of a virtual operator firms may have incentives to change the quality of roaming after investments have been sunk. When a virtual operator is allowed to enter, this commitment problem is eliminated, and firms have no incentives to change the quality of roaming after investments are sunk.

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[21] The proof of this result involves messy, but straightforward algebraic manipulations.

4 Concluding remarks

We have discussed roaming policy (both voluntary and mandatory), and we have also briefly discussed some competition policy aspects related to sharing infrastructure in the mobile communications market. In particular, we have focused on the interaction between roaming policy and investment incentives in the third generation mobile networks (e.g. UMTS). We have shown that all involved are better off under collusion provided that roaming quality is set sufficiently high. Furthermore, in our model, the chosen level of roaming quality is indeed sufficiently high in all cases. This implies that when a regulator or competition authority chooses whether collusion at the investment stage should be allowed, they know that in whatever policy they choose with respect to roaming, they can never do worse than allowing collusion. In some of the Nordic countries, major players in the mobile communications market have decided to cooperate in the process of setting up the next generation mobile networks, which corresponds to the collusion case in our model. In danger of stretching our model a little too far, we have shown that such collusion is actually beneficial in terms of welfare. Consequently, competition authorities should not interfere with such cooperation.

When we introduce a virtual operator into the game relying on the facility-based firms for infrastructure access, we find that the relationship between roaming quality and investment incentives is qualitatively different. Furthermore, our findings suggest that there is little scope for regulation of roaming quality when there is a virtual operator present, both under cooperative and non-cooperative investments. This is also different from the case without the virtual operator present, where the social optimum does not correspond to the unregulated outcome if investments are undertaken non-cooperatively.

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