Discussion Paper No. 09-071

Mobile Network Interconnection and Investments

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Non-technical summary
European mobile communication markets are two-stage markets which are composed of the infrastructure (the network and its components) and the service markets (telephony, mobile internet, SMS). In contrast to most other network-based markets there are multiple fully integrated providers which keep their own network and offer services on their network. Following continuously conducted market inspections of the European Commission, the revenue share of pure service providers is (still) below 10 percent in each of the member states.

I concentrate on fully vertically integrated mobile network providers and analyze the effect of investments on wholesale charges for call termination, termination charges, and the amount of off-net traffic, that is the exchanged calling minutes between the investor's and the competitors' networks. If one network provider invests into its network to reduce the costs of service provision (or to increase service quality) it directly influences its offer and its prices. Lower costs enable the investor to reduce its service prices which should increase the traffic volume, what means the amount of calling in terms of the number of calls and duration.

A competitor has to pay a network provider for terminating calls from its networks to the other network. If the provider of the terminating network invests it is able to reduce the termination rate which the other provider has to pay. As termination rates are costs for the other provider, the investment also affects the incoming traffic from competitive networks.

The European Commission asks national regulatory authorities to regulate termination rates based on the so-called long-run incremental cost (LRIC) approach which encourages infrastructure investments. The investment incentive of this regulation scheme has been multiply proven in the literature. I show in a theoretical model that investments increase the amount of incoming traffic both to the investor's and to the competitors' networks. Moreover, the cost-reduction reduces the investor's termination rates. The cost-reduction also lowers the investor's termination rates but increases (in the absence of regulation), reduces (with LRIC regulation) or keeps the competitors' termination rates constant (with standard cost-based or price-cap regulation).

Employing data for the European mobile markets I analyze the theoretical results in a simultaneous estimation approach. While both the effects on off-net traffic and the effect on own termination rates are confirmed, I find a negative effect of investments on competitors' termination rates which cannot be deduced from regulation. Moreover, considering the change in profits from call termination it exists a positive effect on the investor's short-run profits but nearly no effect on competitors' short-run profits though I find a change in termination rates and in incoming traffic to competitors.

The empirical findings question the usually assumed importance of regulation for investment incentives. Moreover, investments and, in particular, the resulting change in off-net traffic volumes seem to be driven by interactions among the network providers.

Das Wichtigste in Kürze

Europäische Mobilfunkmärkte sind zweistufige Märkte, die aus einer Infrastruktur (dem Netz und seinen Komponenten) und dem Dienstemarkt (Telefonie, mobiles Internet, SMS) bestehen. Im Gegensatz zu sehr vielen anderen netzbasierten Märkten existieren in allen nationalen Märkten mehrere vollintegrierte Anbieter, die sowohl über ein eigenes Netz verfügen als auch Dienste auf diesem Netz anbieten. Der Umsatzanteil alternativer Anbieter, die nur Dienste anbieten, ist kontinuierlichen Marktuntersuchungen der Europäischen Kommission zufolge sehr gering (weniger als 10 Prozent bisher).

Ich konzentriere mich auf die vollständig vertikal integrierten Mobilfunknetzbetreiber und untersuche in diesem Papier die Auswirkung von Investitionen auf die geforderten Großhandelsgebühren für Anrufe des Investors und der Wettbewerber zu einem anderen Anbieter und auf den Verkehr zwischen dem Netz des Investors und denen alternativer Anbieter. Investiert ein Netzbetreiber in sein Netz, um die Kosten des Diensteangebots zu senken (oder die Qualität zu erhöhen), wirkt sich dies unmittelbar auf sein eigenes Diensteangebot und seine Preise aus. Da die Kosten gesunken sind, kann er seinen Preis für die Bereitstellung seiner Vermittlungsleistung senken. Dies wiederum sollte sich positiv auf die nachgefragte Menge, das Verkehrsvolumen, als Anzahl an Telefonaten und deren Dauer, auswirken.

Für die Terminierung von Anrufen aus anderen Netzen, müssen die Wettbewerber dem Betreiber des Empfängernetzes ein Terminierungsentgelt entrichten. Investiert dieser in sein Netz, kann er auch dieses Terminierungsentgelt senken. Da das Terminierungsentgelt Kosten für die Wettbewerber darstellt, wirkt sich die Investition auch auf den eingehenden Verkehr von Wettbewerbern aus.

Die Europäische Kommission fordert, dass das Terminierungsentgelt auf nationaler Ebene nach dem sogenannten long-run incremental cost (LRIC) Ansatz reguliert wird, der insbesondere Infrastrukturinvestitionen fördert. Dass dieser Ansatz Investitionsanreize schafft, wurde bereits mehrfach in der theoretischen Literatur belegt. Zunächst wird in einem theoretischen Modell gezeigt, dass Investitionen das Volumen eingehender Anrufe sowohl beim Investor als auch bei seinen Wettbewerbern steigern sollten. Die Kostenreduktion senkt das Terminierungsentgelt des Investors und erhöht (ohne Regulierung), senkt (bei LRIC Regulierung) oder verändert nicht (bei standardmäßiger kostenorientierter und Preis-Deckel-Regulierung) das Terminierungsentgelt der Wettbewerber.

Anschließend werden die theoretischen Ergebnisse für europäische Mobilfunkmärkte empirisch untersucht. Während der positive Effekt auf das Verkehrsvolumen und der negative Effekt auf das Terminierungsentgelt des Investors nicht widerlegt werden können, sinkt das Terminierungsentgelte von Wettbewerbern. Dies kann allerdings nicht auf die Regulierungsmaßnahme zurückgeführt werden. Bei der Untersuchung der Auswirkung auf den Gewinn aus der Terminierung von Anrufen fällt auf, dass sich der Gewinn des Investors erhöht, der Gewinn der Wettbewerber aber trotz Veränderungen des geforderten Terminierungsentgelts und des Volumens eingehender Anrufe annähernd unverändert bleibt.

Die empirischen Ergebnisse stellen den häufig angenommenen starken Einfluss von Regulierung auf Investitionen in Frage. Vielmehr scheinen Investitionen und daraus resultierende Veränderungen des Verkehrsvolumens zwischen Netzen durch die Interaktion der Wettbewerber geprägt zu sein.

Mobile Network Interconnection and Investments

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Abstract In markets with competing interconnected networks like mobile telecommunication markets investments affect the investor's and also any competitors' profits. In a theoretical model it is shown that cost-reducing investments reduce the investor's termination rates and increase competitors' termination rates under the calling-party-network-pays regime. Moreover, investments increase off-net traffic from the investor's network but also from competitors' networks. Regulation changes the effect on competitors' termination rates but all other effects remain the same or are strengthened. Empirical results support the theoretical findings concerning the investor's termination rates and the findings on off-net traffic. Competitors' termination rates decrease. The negative termination rate effect even outweighs the quantity effect in the competitors' profit functions. Testing for a common regulation-investment effect provides evidence that the negative investment externality is not due to regulation.

Keywords regulation, mobile telecommunications, investments, interconnection
JEL Classification L51, L52, L86, L96, O31, O33

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[*]I would like to thank Jürgen Weigand, WHU - Otto Beisheim School of Management, Glenn Woroch, University of California Berkeley, and my collegues Georg Licht, Helmut Fryges and Kai Hüschelrath for helpful comments. I gratefully acknowledge financial and data support from Deutsche Telekom AG.

1 Introduction

Interconnection is an ongoing issue for competition and regulation authorities in network-based markets. I address the topic of wholesale-price regulation and investments in European mobile telecommunication markets and analyze how investments affect termination rates and off-net traffic. Following Article 8(2) of the Framework Directive (2002/21/EC) "national regulatory authorities shall promote competition [...] by encouraging efficient investment in infrastructure, and promoting innovation". Very recently, the European Commission took up this topic again and proposed to implement long-run incremental cost (LRIC) regulation in mobile voice call termination markets (Market 16 following the latest market definition of the European Commission). LRIC regulation should particularly encourage investment incentives as all providers' termination rates depend on the most efficient infrastructure elements.

Nevertheless, the topic of investments with interconnected networks has, at least to my knowledge, never been addressed in the empirical literature on network competition. There is only little empirical evidence, focusing either on telecommunication markets as a whole or on the effect of competition on investments.[1] Consequently, we only know from theory how mobile network providers, i.e. network providers in markets with comparably low market concentration, should interact. With this paper I want to provide more insight into the issue of investment spill-overs in mobile markets.

I focus on (transportation) cost-reducing/cost-efficiency-increasing infrastructure investments and analyze how regulation affects the impact of investments on mobile network providers' wholesale profits. While quality-increasing investments, as discussed in Foros (2004), Kotakorpi (2006) or Valletti and Cambini (2005), induce a change in customers' calling behavior cost-reducing investments address the supply side. Lower costs enable a provider to offer "more" origination and termination service on its network as both existing facilities can be used more efficiently and the challenge of bottlenecks is mitigated. Note that one cannot easily separate investments in quality from cost-reducing investments. I concentrate on cost-reducing investments due to the measurable direct effect of cost changes on changes in termination rates and draw links to the topic of quality investments where it is possible.

If one provider invests in its network this should also affect termination rates, quantities and thus profits of other providers. First, investments in cost-reduction lower

[1] Central exemptions are Röller and Waverman (2001) or also Grajek and Röller (2008).

the own termination rates (see e.g. Armstrong (2002)). As termination rates are costs for competitors one should expect investments also to affect competitors' calls to other networks (see Valletti and Cambini (2005)). Second, the cost-reduction changes the investor's amount of outgoing traffic because lower retail prices induce customers to increase their demand for outgoing calls.

I consider these hypotheses under alternative pricing schemes (linear and non-linear) and compare the results assuming alternative forms of regulation which are in place in European countries. Afterwards the theoretical findings will be analyzed by adopting data for the EU 15 countries as well as for Norway and Switzerland. I keep the models as close as possible to the standard theoretical literature (among others Armstrong (1998), Laffont, Rey and Tirole (1998a and b), Carter and Wright (2003)) and adopt the assumptions and approaches provided. This way, comparisons of the empirical outcomes with the theoretical findings are facilitated and, moreover, also comparisons with the results of investment effects expected from the literature are allowed for.

In the theoretical part I assume a three-step model with asymmetric players which mainly corresponds to the model in Dewenter and Haucap (2005).[2] In doing so a positive investment effect on own profits is found but also a positive externality on competitors' off-net profits from incoming calls. While non-linear pricing provides similar results as linear pricing, regulation (as assumed in the literature) ignores network externalities leading to a deterrence of competitors' prices and traffic.

With the empirical model I find support that investments reduce the investor's termination rate and increase the investor's incoming traffic. As the traffic effect outweighs the effect on termination rates in the investor's short-run profit function the empirical results support the results expected from the theoretical model. Moreover, investments increase competitors' incoming traffic and reduce their termination rates. Replacing the regulation control variables by interaction terms with investments shows that the negative effect on competitors' termination rates is not due to regulation. Combining the empirical findings with the theoretical model the (pure) investment-induced termination rate reduction even outweighs the price-driven traffic increase in the competitors' profit functions.

[2] I rely on the central assumptions in this paper as, to my knowledge, it is the first paper which analyzes an issue in mobile network competition from both a theoretical and an empirical perspective.

The paper is organized as follows: The next section provides an overview over the existing literature on off-net mobile competition. Afterwards I introduce the theoretical model. Hypotheses are derived which will be tested for the EU 15 countries as well as for Norway and Switzerland. In section 4 the alternative estimation approaches are introduced and compared with regard to alternative estimation outcomes. Section 5 provides the estimation results and discusses them in more detail. Section 6 concludes and provides ideas for further extensions.

2 Literature Review

Alternative aspects of mobile interconnection have been analyzed in an extensive range of literature which is mainly based on the framework of three seminal papers, Armstrong (1998), Laffont, Rey and Tirole (1998a) and Laffont, Rey and Tirole (1998b), hereafter A-LRT. Assuming a symmetric two-provider model, the papers provide insight into multiple fundamental outcomes concerning competition in network-based markets and open a wide range for extending research. Concerning off-net traffic Laffont et al. (1998a) show that in a common per-unit pricing system the increase in total outgoing traffic corresponds to a reduction in incoming traffic. Thus, one provider's decision to reduce off-net prices is a decision at the margin. Alternatively, allowing for on-net/off-net price discrimination network providers choose higher off-net prices, thus, affecting customers' network choice as shown in Laffont et al. (1998b). In consequence, a raising-rivals-costs strategy in the sense of increasing termination rates need not result in a change of retail prices but in a promotion of competition for market shares.
The issue of infrastructure investments in network-based markets has been analyzed in a comparably low number of papers mostly assuming a vertically integrated upstream monopolist competing with one or more downstream entrants. Central results of these papers have been proved to exist also with network competition. Foros (2004) shows for a vertically integrated upstream monopolist and a downstream retailer that the level of quality investments depends on the substitutability of downstream services. The higher the degree of substitutability the lower is the investment incentive for the network provider. Foros assumes investments to take place before the regulation stage. As the investor does not know the implemented regulation in advance the under-investment challenge becomes even stronger with regulation than in the situation with no regulation which negatively affects total welfare. On the other hand, if downstream substitutabil-

ity is comparably low investments are used to force competitors out of the market. Kotakorpi (2006) also finds support for the under-investment problem with downstream substitutability. Following Kotakorpi network competition eliminates the foreclosure challenge of the upstream monopoly. Though, the long-run under-investment problem still remains in place.

Cambini and Valletti (2005) adopt the analysis of investment incentives to the framework of network competition by introducing an investment stage to the standard A-LRT model. The central assumption is that investments increase quality but do not affect per-unit costs (as in Foros (2004) and Kotakorpi (2006)). They show that with asymmetric network size a small firm would benefit from a mark-up of termination rates over costs whereas the larger competitor would lose. With a lower level of substitutability between the services offered by the operators both providers would reduce investments with termination rates above costs. Nevertheless, without regulation competitors would negotiate a termination rate above per-unit costs which reduces the incentive to invest in quality increase.

I will keep these central findings from theory in mind when analyzing the impact of investment spill-overs. As there exists nearly no empirical analysis of the theoretical findings I try to provide some more insight into the interplay of competitors in mobile markets by adopting the theoretical findings on the effects of investments on off-net prices and traffic into an empirical framework.

3 Theoretical Model

In this section I derive a theoretical model for short-run profits where I assume market shares as given. I start with the more restricted linear pricing model and show how termination rates and quantities change due to investments in cost-reduction. Then I compare the results of the linear pricing model with the outcome under two-part tariff pricing. Finally, termination rates are fixed at a constant level due to regulation (i.e. either at per-unit costs/at a constant rate above per-unit costs or at a cost-independent level). I employ a simplified version of the model in Dewenter and Haucap (2005) and use comparative statics to analyze alternative effects of investments on termination rates and traffic in terms of total minutes of usage (MOU).

Consider a market with a countable number of MNPs i, $i = 1, ..., N$, $i \neq -i$. Customers are of mass 1 and have randomly chosen one MNP. As in Dewenter and Haucap (2005) customers receive the same gross-utility a from calling but no utility from being called.[3] Calls are assumed to be balanced across customers.
Each customer in network i demands $a - b(s_i)p_{i,j} = a - b_i p_{i,j}$ calling minutes to customers in network j, $j = 1, ..., N$, $i \neq j$, where $p_{i,j}$ is the per-minute price for outgoing calls to network j, b_i is a scale parameter for price-elasticity increasing in the investor's market share s_i, $b'(s_i) > 0$. The larger b_i the lower is the willingness to pay for one unit of off-net calling. As I will only consider off-net traffic the on-net/off-net pricing strategies and the utility of being with a particular MNP need not be further specified. Customers only decide on the call length dependent on prices. The short-run demand function deviates from the model in Dewenter and Haucap (2005) where the representative off-net demand depends on the average off-net prices weighted by competitors' market shares.[4]
MNPs are active in a calling-party-network-pays regime (cpp regime). The per-minute termination rate t_i is the wholesale price which one MNP asks another for terminating a call. The per-unit costs c_i are identical for call origination and termination (as assumed in A-LRT). Finally, I assume the long-run market to be sufficiently less concentrated. For this setting this means $s_i < 2 \sum_{-i} s_{-i} \frac{b_{-i}}{b_i}$.

3.1 Short-run price choice

With a linear pricing scheme provider i's short-run off-net profits from call origination and termination are given by:

$$\begin{aligned} \pi_i(p_{i,j}, t_i) = \sum_j \pi^i_{i,j} + \sum_j \pi^i_{j,i} = \sum_j \left((p_{i,j} - t_j - c_i) s_i s_j (a - b_i p_{i,j}) \right) \\ + \sum_j \left((t_i - c_i) s_i s_j (a - b_j p_{j,i}) \right) \end{aligned} \tag{1}$$

[3]For the analysis of quality investments one could think of identical gross-utilities for customers per provider a_i.
[4]A more detailed discussion on customers demand for off-net calls can be found in Dewenter and Haucap (2005) and Hoernig (2007). Nevertheless, it is obvious that by adopting Dewenter and Haucap's assumptions, $b_i = b_j = b$ and $p_i = c_i$, one receives similar results with the model of this paper.

$\sum_j \pi^i_{i,j}$ are retail profits from outgoing traffic, $\sum_j \pi^i_{j,i}$ are wholesale profits from incoming traffic. Off-net call prices depend on the termination network. While termination rates are set equally for all incoming calls, retail prices for off-net calls are chosen dependent on the termination rates of the called network.

Let us assume a three stage game where, first, MNPs decide on investments, afterwards they choose termination rates t_i and then decide on retail off-net prices. Customers choose their amount of off-net communication dependent on their provider's retail off-net price. Using backward induction optimum retail prices and termination rates will be derived. With the structure assumed here I follow Dewenter and Haucap and ignore the possible long-run strategy for a termination rate choice. The long-run termination rate choice is the focal subject of many theoretical papers beginning with the seminal work of A-LRT and Gans and King (2001) from a time-independent perspective and with a time-dependent perspective in Hoeffler (2007).

Deriving (1) one gets i's profit-maximizing off-net price:

$$p_{i,j} = \frac{a}{2b_i} + \frac{c_i + t_j}{2} \tag{2}$$

Note that provider i only partially passes through termination rates to its customers. Replacing prices for off-net calls and deriving the resulting profit function with respect to termination rates yields:

$$t_i = \frac{c_i}{2} + \frac{\sum_j s_j(a - b_j c_j)}{2\sum_j s_j b_j} \tag{3}$$

3.2 Investments

As we cannot analyze the equilibrium investment behavior of MNPs in the empirical part of the paper, I use comparative statics here considering the effect of investments on the investor's termination rate, retail prices and off-net traffic and the externality of investments on competitors' off-net profits. I concentrate on investments in cost-reduction k_i and assume $c_i'(k_i) < 0$. The reasoning behind this assumption is that cost-reducing/cost-efficiency increasing investments are only implemented if the cost level taking into account depreciation is reduced.

In what follows two alternative investment effects are compared:[5] The **own investment effect** represents the effect of investments on the investor's profits from off-net traffic. As the demand for off-net calls depends on off-net retail prices cost-reducing investments affect the investors off-net profits both through wholesale and retail prices and through the quantity of incoming and outgoing calls.

With the term **investment externalities** the impact of one provider's investment on another provider's off-net profits from interconnection with the investor is described.

Notational note: In the following the investing network is indexed by i and $-i$ is used for all networks except for i and $-j$ for all networks except for $j \neq i$.

Own investment effect

Deriving (3) with respect to k_i yields the change in the termination rate for incoming calls on network i:

$$\frac{\partial t_i}{\partial k_i} = \frac{c_i'(k_i)}{2} < 0 \tag{4}$$

As expected for monopoly prices, the termination rate decreases by cost-reduction. Moreover, the cost-reduction is only partially passed on to customers. From (2) we know that the effect of investments on the off-net price $p_{j,i}$ is $\frac{1}{2}t_i'(k_i)$. The investment increases the amount of traffic from network j to network i because the impact on off-net prices is strictly negative.

With lower termination rates a positive effect of investments on own wholesale profits is observed as, first, termination rates decrease less severely than costs and as, second, $p_{j,i}$ for any MNP j also decreases due to the reduction in termination costs:

$$\frac{\partial \sum_j \pi_{j,i}^i}{\partial k_i} = -c_i'(k_i)\frac{s_i}{2}\sum_j \left(s_j \frac{1}{b_j}(a - b_j(t_i + c_j)) \right) > 0 \tag{5}$$

The term in brackets is non-negative for both the linear and the two-part tariff model as we will see below.

The calculation of retail profits from the investor's outgoing calls is provided in appendix A.3.

[5] In appendix A.1 a third investment effect will be discussed which has been ignored in the literature due to the standard assumption of only two competing networks.

Investment externalities

The effect of i's investments on own outgoing traffic depends on i's relative market share. Competitors' termination rates are stronger affected by larger providers' investments as origination costs enter competitors' termination rates weighted by the market share (see (3)). Thus, competitors choose termination rates to be higher the higher the market share of the investor and the stronger the investment effect on origination costs due to the increase in incoming traffic:

$$\frac{\partial t_j}{\partial k_i} = -c_i'(k_i)\frac{s_i b_i}{2\sum_{-j} s_{-j} b_{-j}} > 0 \tag{6}$$

While the impact of investments on incoming calling minutes to the investor is straight forward, the effect on incoming minutes to competitors' networks, $\sum_j q_{i,j} = s_i \frac{1}{b_i} \sum_j s_j \frac{a_i - b_i p_{i,j}}{2}$, is ambiguous. With higher wholesale prices for termination the investor chooses higher retail prices for outgoing calls. On the other hand the efficiency increase reduces origination costs. The total effect therefore depends on whether the efficiency increase outweighs the effect on competitors' termination rates or not. Deriving prices for outgoing calls from the investor's network $p_{i,j}$ with respect to k_i yields:

$$\frac{\partial p_{i,j}}{\partial k_i} = -\frac{c_i'(k_i)}{2}\frac{s_i b_i - 2\sum_{-j} s_{-j} b_{-j}}{2\sum_{-j} s_{-j} b_{-j}} \tag{7}$$

which is negative as the second term is strictly negative (given the assumption of sufficiently low market concentration). Even though competitors' termination rates increase in i's investment the investor does not pass on this termination rate increase to customers. Moreover, the cost-reduction overcompensates the investment effect on competitors' termination rates.

As competitors' costs of call termination on their own network remain unchanged by i's investment competitors' wholesale mark up increases. Additionally, the total duration of incoming calls from the investor's network increases as off-net calls from i are positively affected by i's investment in cost-reduction. Combining these findings the investment externality on competitors' wholesale profits is positive:

$$
\frac{\partial \pi^j_{i,j}}{\partial k_i} = -\frac{c'_i(k_i)}{2} s_i s_j \left(\frac{s_i}{2\sum_{-j} s_{-j} b_{-j}} (a - b_i(c_i + t_j)) \right.
$$
$$
\left. + (t_j - c_j)\left(1 - \frac{s_i}{2\sum_{-j} s_{-j} b_{-j}}\right)\right) > 0 \tag{8}
$$

I show in appendix A.3 that also the effect on competitors' retail profits is positive.

In a nutshell, we have identified a positive own wholesale profit effect as the cost-reduction raises the price-cost margin and – by reducing competitors' off-net prices – increases the demand for incoming calls. Furthermore, we have identified a positive externality on competitors' wholesale profit: First, with lower off-net retail prices calling minutes from the investor's network increase and, second, competitors' termination rates increase with lower origination costs.

3.3 Comparison to Two-Part Tariffs

Similar investment effects as found with the linear pricing model are not necessarily found with alternative pricing schemes. One commonly used approach in the literature are two part-tariffs with per-unit prices equal to termination rates plus origination costs (e.g. A-LRT, Wright (2002), Armstrong (2002)). Furthermore, assuming cost-based regulation forces termination rates to be set at per-unit costs of call termination. Valletti and Cambini (2005) also allow for termination rates at a fixed level above marginal costs. With these alternative/additional assumptions about a fixed termination rate investment effects change as follows:
If the retail price for outgoing calls to network i is fixed at termination rate plus origination costs, $p_{j,i} = t_i + c_j$, changes in termination rates are directly passed on to customers' demand choice. Thus, the investor's termination rate reduction increases the demand for outgoing calls to network i.
Is the change in termination rates completely passed on to the demand for outgoing calls? If this is the case it induces the following change in demand for calls to network i and for calls from network i (with unrestricted termination rates):

$$
\begin{aligned}
\frac{\partial \sum_j q_{j,i}}{\partial k_i} &= c'_i(k_i) \sum_j \frac{\partial q_{j,i}}{\partial p_{j,i}} \frac{\partial p_{j,i}}{\partial c_i} = -\frac{c'_i(k_i)}{2} s_i \sum_j s_j b_j \\
\frac{\partial \sum_j q_{i,j}}{\partial k_i} &= -c'_i(k_i) s_i b_i \sum_j s_j \left(1 - \frac{s_i b_i}{2\sum_{-j} s_{-j} b_{-j}}\right)
\end{aligned} \tag{9}
$$

With termination rates fixed to costs the change in demand is:

$$\begin{array}{l} \frac{\partial \sum_j q_{j,i}}{\partial k_i} = -c_i'(k_i) s_i \sum_j s_j b_j \\ \frac{\partial \sum_j q_{i,j}}{\partial k_i} = -c_i'(k_i) s_i (1 - s_i) b_i \end{array} \tag{10}$$

The demand effect is twice the demand effect with linear prices. With the additional assumption of termination rates equal to per-minute costs it is four times the effect. This excess demand increase does not change j's off-net profit as retail prices are at per-unit costs.

So far I have ignored the impact on the subscription fee. With a lower per-unit price the subscription fee is set higher dependent on the (expected) increase in consumer surplus. As Peitz (2005) states:

"In a neighborhood around cost-based access prices an increase in the competitor's [entrant's] access price leads to lower subscription fees of any [both] operators."[6]

Taking for example the model of Peitz (2005) one can easily show that the investor's and a competitor's subscription fee rise due to investments. Corresponding results could be derived for the investment effect on own profits from outgoing calls and also for an indirect investment effect on outgoing calls.

In praxis the traffic-independent subscription fee of two-part tariff schemes cannot be adjusted as fast as the per-unit price. The adjustment delay is due to contract duration with customers and overlapping beginnings of contract periods. As investments do not have a one-shot property but, moreover, are conducted continuously one should either expect ongoing re-adjustments of subscription fees or, alternatively, per-unit prices above per-unit costs as a second-best option. Contract adjustments are not implausible even during the contract period if providers benefit from lower retail prices, for example due to own or competitors' investments.

3.4 Regulation

With the transition of the competition enforcing regulation directives to national law in 2004 and 2005 mobile termination markets have been regulated in all EU member states at the latest. Nevertheless, the directives do not specify which regulation scheme should be adopted. In European countries mainly two alternative regulation schemes have been in place since 2000. Cost-based regulation like LR(A)IC is the most wide-spread ap-

[6]Peitz (2005), p. 9. Peitz considers the two-provider-case.

proach and is the one which the EC proposes to be extended for mobile communication markets in a recommendation of 07 May 2009.[7] The alternative regulation scheme is incentive regulation meaning either price- or revenue-cap regulation. Table 1 provides an overview of the alternative regulation approaches which are in place in Europe.

Cost-based regulation forces termination rates to be chosen at cost-level or a constant mark-up above costs. With cost-based termination rates investments in cost-reduction are directly passed on to the investor's termination rates. While the investment externalities on incoming calls are higher with cost-based regulation than without regulation the wholesale price-cost margin remains constant. Concerning the effect on profits from outgoing calls to the investor a stronger reduction in retail prices is observed since the mitigating effect of cost-reduction on optimally chosen termination rates is abolished. The price effect is overcompensated in the competitors' profit functions by a higher demand for outgoing calls. Note that LRIC regulation as it is usually defined in the literature is a simplification of the more technical definition as it is given in Laffont and Tirole (2001):

"LRIC=Marginal cost of date-t production of the most efficient technology × (Interest rate + Rate of technological progress + Rate of physical depreciation of the equipment)"[8]

If LRIC regulation were introduced in the strict sense competitors were forced to reduce their termination rates in line with an investment. In consequence, this would deter the outcome twice: First, the investor's retail price would decrease more than without regulation and even more than with standard cost-based or incentive regulation as the competitors' termination rate reduction stronger affects the investor's price-cost margin. Second, the competitors' wholesale price-cost margin would also be deterred increasing the off-net traffic between competitors. Thus, under LRIC regulation the strategic-instrument-character of investments is enhanced in the short-run (increasing incoming traffic and reducing competitors' profit margins). In contrast, with standard cost-based regulation direct investment effects vanish as termination rates are unaffected by competitors' investments but are in place with the LRIC form.

With price-cap regulation an upper bound for termination rates is set by the regulator based on a price basket of telecommunication services. Thus, by investing in cost-reduction MNPs directly gain from a higher wholesale price-cost margin. Nevertheless,

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[7] `http://europa.eu/rapid/pressReleasesAction.do?reference=IP/09/710&format=HTML&aged=0&language=EN&guiLanguage=en`

[8] see Laffont and Tirole (2001), p. 151

Table 1: Mobile Regulation in the EU 15, Norway and Switzerland[9]

	cost-based	incentive	cost-based	incentive	cost-based	incentive
	2001		2004		2007	
Austria					X	
Belgium						X
Denmark						X
Finland	X		X		X	
France					X	
Germany					X	
Greece					X	
Ireland					X	
Italy		X		X		X
Netherlands					X	
Norway					X	
Portugal						X
Spain					X	
Sweden		X		X	X	
Switzerland					X	
United Kingdom		X		X		X

the incoming traffic remains unaffected as long as the individually optimal termination rate is higher than the upper bound. The adoption of price-cap regulation to the model results in a stronger investment effect on the wholesale price-cost mark up than in the absence of regulation as termination rates are fixed. Thus, the investment effect on profits from incoming calls is similar to standard cost-based regulation. The wholesale mark up changes only due to the cost-reduction but not because of an increase in incoming calls. As termination rates are fixed for every provider separately investment externalities under a price-cap regulation scheme only consist of an increase in traffic. All other variables (competitors' retail prices, termination rates and outgoing traffic) are unaffected by investments. Indirect investment effects vanish as termination rates are independent of competitors' traffic.

Under a two-part tariff pricing scheme with per-unit prices at cost-level we still observe positive investment effects on the traffic from and to the investor. One exception is incoming calls under an incentive regulation scheme because the investor's termination rates are unaffected by the investment. The cost-reduction increases investor's traffic-dependent profits only for incoming traffic under price-cap regulation as the termination rate level is allowed to be above costs. Similarly, there is a positive externality on competitors' traffic-dependent profit only for incoming traffic under the price-cap scheme.

[9]Information taken from the Plaut Economics Regulatory Index (Zenhäuser et al. (2007)) and alternative regulators' websites.

In a nutshell, regulation is expected to introduce a deterrence to investment effects as it fixes price components either to a cost-based level or to an exogenously given price basket. Thus, under cost-based regulation the investment effect on competitors' prices is larger whereas the effect on the investor's prices remains equal to that of the situation without regulation. With the incentive regulation the own retail price effect is equal to the situation without regulation but no effect on competitors' prices exists anymore.

3.5 Discussion of the theoretical model

As a potential equilibrium situation cannot be analyzed with the data I only consider the impact of investments on own wholesale profits and the externality on competitors' wholesale profits in the short-run. Thus, I do not fully specify the theoretical model in the sense that I only analyze off-net traffic and ignore on-net effects of investments and the substitutability between on-net and off-net calls.[10] Second, I use comparative statics to analyze the impact of investments and do not further discuss investment costs. In consequence, the strategic investment behavior as it is discussed in Valletti and Cambini (2005) is ignored here. In doing so I mainly refrain from the analysis of size effects in terms of market shares and ignore customers' provider choice.

Even with these limitations the theoretical model provides two central results concerning the impact of investments on termination rates and off-net traffic. From the own investment effect analysis investments should reduce own termination rates, thus, increasing the demand for calls to the investor both assuming either regulation or the absence of regulation. Note that the demand increase is only induced by the termination rate reduction. Thus, the cost-reduction is only partially passed on to customers with both a linear and a two-part tariff pricing structure.

H1 (Own investment effect): Investments reduce own termination rates but affect incoming traffic only through the investor's termination rate choice.

After the analysis of the own investment effects we turned to the effect of investments on competitors' termination rates and competitors' incoming calls. The demand for outgoing calls, i.e. the total incoming calls to competitors, increases in line with cost-reducing investments, as the cost-reduction results in lower retail off-net prices from the investor's network. Due to this demand increase competitors are able to ask for higher termination

[10] The on-net/off-net price differential problematic was, to my knowledge, first introduced in A-LRT and is the subject of Hoernig (2007).

rates. Taking into account regulation we should expect either no significant effect on competitors' termination rates or a reduction in termination rates. The impact on the amount of incoming traffic to competitors is still positive.

H2a (Investment externality without regulation): Investments increase competitors' termination rates and directly increase the incoming traffic to the competitors' networks.
H2b (Investment externality with regulation): Investments either have no effect on competitors' termination rates (standard cost-based, incentive) or reduce competitors' termination rates (LRIC) and directly increase the incoming traffic to the competitors' networks.

As mobile contract conditions could be adjusted only in the long-run I expect to find these effects independently of the pricing structure. The effect on termination rates might be reduced in the long-run but should still be observed.[11]

4 Empirical Analysis

In order to test the hypotheses I employ data for the EU 15, as well as for the Norwegian and the Swiss mobile wholesale markets. I first derive an econometric model which is closely related to the theoretical model of the previous section. Afterwards I shortly describe the data and the expected signs of the estimation coefficients. The data selection, the description of some pitfalls with the data and also the way of data adjustments is provided in appendix A.4 and A.5.

4.1 Econometric Model

Both hypotheses consist of two parts, one concerning price effects and one concerning traffic. It is therefore important to disentangle both effects. Two separate equations are used to explain the effect of investments on termination rates and on incoming traffic. Furthermore, two alternative equation systems are used for the first and for the second hypothesis as two alternative effects of investments are tested.

[11] Note that I refrain from hypotheses on off-net profits as due to data availability off-net profits have to be derived from the available variables. Nevertheless, the impact of investments on off-net profits will be further discussed in an extension to section 5.

Dewenter and Haucap (2005) provide a very promising approach for estimating termination rates. They use measures for market concentration and market size and control variables for technology and regulation as well as country and year effects. I adopt this approach and additionally include an investment parameter to get the following equation for the analysis of the own investment effect on termination rates:

$$\begin{aligned} log(t^1_{i,l,z}) = \alpha^{t1}_{l,z} + \beta^{t1}_{inv} log(investment_{i,l,z}) + \beta^{t1}_{s} log(s_{i,l,z}) + \beta^{t1}_{msize} log(msize_{l,z}) \\ + \beta^{t1}_{urbpop} log(share\ upop_{l,z}) + regulation'_{i,l,z} \beta^{t1}_{reg} + \beta^{t1}_{1800} GSM1800_{i,l,z} + \epsilon^{t1}_{i,l,z} \end{aligned} \tag{11}$$

where i is a firm index, l is a country index and z is a year index. Dewenter and Haucap have also added the Herfindahl-Hirshman-Index (HHI) as a control variable and argue that they have expected to find a significant impact of concentration on termination rates. Nevertheless, the explanatory power of the HHI in their estimations might be reduced due to the high correlation with the market share variables. Because of this issue in the estimation specification and as it is found to have no significant effect on termination rates I ignore it in the estimation approach. s is the individual market share in terms of customers, $msize$ is the total number of mobile subscribers in a country. The share of urban population $share\ upop$ is introduced as termination costs are expected to depend on the population concentration. With a higher concentration termination costs should be lower, thus, negatively affecting termination rates. Similar to Dewenter and Haucap (2005) I introduce a $GSM1800$ dummy to control for providers which only offer communication via the higher, more expensive frequency level. As there is more detailed information available about the alternative regulation schemes I add regulation dummies for cost-based, incentive and asymmetric regulation, instead of the approach provided in Dewenter and Haucap.

The equation for the amount of incoming traffic to the investor is specified as follows:

$$\begin{aligned} log\left(\sum_j q^1_{j,i,l,z}\right) = \alpha^{q1}_{l,z} + \beta^{q1}_{inv} log(investment_{i,l,z}) + \beta^{q1}_{t} log(t_{i,l,z}) + \beta^{q1}_{s} log(s_{i,l,z}) \\ + \beta^{q1}_{msize} log(msize_{l,z}) + \beta^{q1}_{post} post_{i,l,z} + \beta^{q1}_{urbpop} log(share\ upop_{l,z}) \\ + regulation'_{i,l,z} \beta^{q1}_{reg} + \epsilon^{q1}_{i,l,z} \end{aligned} \tag{12}$$

Besides the variables of the termination rate equation I include termination rates and a post-paid dummy into the quantity equation. From the theoretical model one should expect a negative coefficient of the termination rate term. Also a positive coefficient of the post-paid term is expected.
Equations (11) and (12) will be used in line with the first hypothesis on own investment effects.
For the second hypothesis I aggregate the data with regard to investments. Although it was not necessary to consider multiple investors simultaneously in the theoretical model it is important to take this aspect into account in the empirical analysis. As an individual investment effect of one provider cannot be isolated from those of others, I use a weighted average measure of investments as an explanatory variable for the analysis of a potential externality. In order to make comparisons with the results of the first equation system easier we take the perspective of a competitor and consider how aggregated investments affect termination rates and incoming traffic.[12] Thus, we get for the termination rate equation and the incoming traffic equation:

$$\begin{aligned} log(t^2_{i,l,z}) = {} & \alpha^{t2}_{l,z} + \beta^{t2}_{inv} log\left(\sum_j \frac{investment_{j,l,z}}{(N-1)_{l,z}}\right) + \beta^{t2}_{s} log(s_{i,l,z}) \\ & + \beta^{t2}_{msize} log(msize_{l,z}) + \beta^{t2}_{urbpop} log(share\ upop_{l,z}) + regulation'_{i,l,z}\beta^{t2}_{reg} \\ & + \beta^{t2}_{1800} GSM1800_{i,l,z} + \epsilon^{t2}_{i,l,z} \end{aligned} \tag{13}$$

$$\begin{aligned} log\left(\sum_j q^2_{j,i,l,z}\right) = {} & \alpha^{q2}_{l,z} + \beta^{q2}_{inv} log\left(\sum_j \frac{investment_{j,l,z}}{(N-1)_{l,z}}\right) + \beta^{q2}_{t} log(t_{i,l,z}) \\ & + \beta^{q2}_{s} log(s_{i,l,z}) + \beta^{q2}_{msize} log(msize_{l,z}) + \beta^{q2}_{post} post_{i,l,z} \\ & + \beta^{q2}_{urbpop} log(share\ upop_{l,z}) + regulation'_{i,l,z}\beta^{q2}_{reg} + \epsilon^{q2}_{i,l,z} \end{aligned} \tag{14}$$

where $log(\sum_j \frac{investment_{j,l,z}}{(N-1)_{l,z}})$ is the logarithm of the average investment of all MNPs except for i. All other variables are equal to those of the first empirical model. Due to lags in the data employing a time dependent approach would heavily suffer from the low number of observations. I therefore pool the data and use similar estimation approaches as in Dewenter and Haucap (2005).

[12] Alternatively, one could also take the perspective of an investor and look at how investments affect outgoing traffic and the competitors' termination rates.

4.2 Data Description and Data Adjustments

Data from multiple sources is employed including information about the fully vertically integrated MNPs in the EU 15 as well as Norway and Switzerland, data about termination regulation and the termination rates, information about individual transmission technology per provider and data about population concentration on a quarterly basis between 2001 and 2007.[13] Unfortunately, due to lags in the data structure we have to ignore Greece and Luxembourg in the estimations. As not all information is provided in the form required for the analysis I adjust the data.[14] The most-relevant adjustment is the calculation of incoming calling minutes. Among other sources data from the Merrill Lynch European Wireless Matrix is used which provides only aggregated data on calling minutes and does not distinguish on-net traffic from off-net traffic. Furthermore, it is stated in the data description that due to double-counting of incoming and outgoing calls total calling minutes are upward-distorted.[15] I correct the data using standard approaches known from the theoretical literature (e.g. A-LRT). Usually, separating on-net from off-net traffic is done on the basis of market shares assuming a balanced calling scheme. The total off-net traffic originating from MNP j is calculated as one minus the own market share times the total minutes of usage:

$$q_{j,l,z} = (1 - s_{j,l,z})MOU_{j,l,z}$$

where $MOU_{j,l,z}$ are the total minutes of usage of MNP j. The higher the individual market share the more outgoing calls are terminated on the own network.

From these adjusted values I calculate the quantity of incoming calls to any network i as

$$\begin{aligned} \textstyle\sum_j q_{j,i,l,z} &= \textstyle\sum_j \frac{s_{i,l,z}}{1-s_{j,l,z}} q_{j,l,z} \\ &= s_{i,l,z} \textstyle\sum_j MOU_{j,l,z} \end{aligned} \qquad (15)$$

As in Dewenter and Haucap (2005) information on costs of call termination is proxied with variables like population concentration and a dummy for GSM 1800 technology. The dummy takes the value 1 if the provider offers mobile services only in the frequency band around 1800 MHz. If the provider also offers mobile services in the 900 MHz frequency band or only in this lower frequency band the dummy takes the value of 0.

[13]I appreciate the comprehensive support with data access to the Deutsche Telekom AG which enabled the access to non-publicly available information on traffic, company-specific information and termination rates.

[14]The description of raw data adjustments is provided in appendix A.4 and A.5.

[15]See p. 18 of the Merrill Lynch European Wireless Matrix 2007.

Many European MNPs are active in multiple countries or are organizationally linked across countries. Thus, one might think of competitive advantages of these providers over competitors in national markets because of economies of scale on the organizational or technical level or because of the opportunity of cross-subsidizing investments. I have controlled for multi-national activities including company dummies and dummies for multi-national activities in the estimation equations and I have used Hausman specification tests for comparing the results of the restricted and the unrestricted models. In doing so I could not identify a significant additional company-specific effect as well as no significant difference between multi-national MNPs and national MNPs.
One outstanding issue in the empirical investment analysis are delays in investment effects. That is why one should use investments in a lagged form (Greenstein (2005), Friederiszick et al. (2008)). I have tested alternative lag lengths also considering cyclical investment effects. In doing so I could identify a four-period investment cycle. Nevertheless, correcting for cyclical investment effects brings us to no significant deviation to the model where one assumes contemporaneous investment effects. Moreover, with a time-variant approach I get results which are strongly driven by a lower number of observations.

Table 2 provides an overview over the data for the first and the last year of the estimation period. Off-net traffic increases during the observation period by about 50 percent what is, in my opinion, driven by mainly three factors: First, we observe an ongoing increase in the number of mobile users in all countries over the observation period at a decreasing growth rate over time what means that the saturation point of mobile communication has not been reached yet (see OECD Communications Outlook 2007, chapter 4). A second reason might be the change in the contract structure and also in the usage of mobile phones. While in the early 2000s many customers used mobile phones mainly for short calls or for short messages mobile devices changed their character to organizers with music and photo applications. Thus, mobile devices became more important not only for calling services but, moreover, as a standard companion in particular for younger customers. Besides this change in usability mobile communication more and more substitutes and simultaneously complements fixed line telephony. Contract structures in particular at the end of the observation period turned from minutes-based pricing to flat rate offers which allows customers to ignore call length. Before, many customers used

Table 2: Descriptive Statistics

2001	Mean	Std. Dev.	Min	Max	Obs.
MOU incoming (in tsd.)	41.9	26.2	0	132.7	143
termination rate (in cent/min.)	0.328	0.339	0.102	1.240	163
capex (in mio.)	168.4	216.4	38	931	20
market share	0.301	0.173	0.005	0.713	212
market size (in tsd.)	17704.7	18072.4	2508.0	56108.0	212
share urban population	0.741	0.113	0.551	0.972	236
post paid (in tsd. subscr.)*	3154.5	3501.7	283	11770	26
cost regulation	0.068	0.252	0	1	236
price/rev. cap regulation	0.136	0.343	0	1	236
regulation netmonopoly	0	0	0	0	236
GSM 1800	0.102	0.303	0	1	236

2007	Mean	Std. Dev.	Min	Max	Obs.
MOU incoming (in tsd.)	61.0	30.0	0	166.1	120
termination rate (in cent/min.)	0.220	0.251	0.057	0.990	148
capex (in mio.)	103.7	80.6	14	379	138
market share	0.293	0.147	0.031	0.625	156
market size (in tsd.)	30235.2	32120.4	4589	93292.0	153
share urban population	0.753	0.110	0.589	0.973	177
post paid (in tsd. subscr.)	3005.4	3691.5	82	15669	156
cost regulation	0.305	0.462	0	1	177
price/rev. cap regulation	0.339	0.475	0	1	177
regulation netmonopoly	0.356	0.480	0	1	177
GSM 1800	0.102	0.303	0	1	177

* 2002

their mobile phone only if no cheeper fixed line phone was available.[16] Finally, lower off-net costs might be a driver for the increase of traffic as a decrease in calling costs is probably passed on to customers which is also the standard assumption in theoretical models.

The high 2001 observations of capex might be driven by an outlier group in the data set as in the following years investments between 95 and 120 million Euros have been observed. Thus, the exceptionally high average investment level in 2001 is probably not (only) due to the auctioning of or beauty-contests for UMTS licenses. Moreover, it might be induced by missing data on smaller countries for the year 2001.

Concerning market shares we find a slight reduction in market concentrations what is the target of termination regulation. Nevertheless, we do not know whether the reduction in concentration is driven by tougher regulation or whether the reduction goes only in hand with a reduction in variability, also be seen from the standard deviation.

An overview over the expected estimation outcomes is given in table 3. From the theo-

[16]See e.g. Ward and Woroch (2004).

Table 3: Expected Outcomes

Dependent Var.	own investment effect term. rate	own investment effect MOU inc.	investment externality term. rate	investment externality MOU inc.
termination rate		-		-
capex	-		+/-	+
market share	-	+	-	+
market size		+		+
share urban pop.	-		-	
post paid		+		+
cost regulation	+		+	
price/rev. cap regulation	+		+	
GSM 1800	+		+	

retical model one should expect a negative effect of capex on the investor's termination rate. A positive effect on the competitors' termination rates is expected in the absence of regulation whereas the effect is nil or negative dependent on the underlying regulation scheme. Concerning the effect on off-net traffic one should expect a positive effect on the competitors' incoming traffic. Note that with cost-reducing investments no (additional) investment effect on the investor's incoming calls should be expected as the whole effect on incoming traffic stems from the change in the termination rate due to investments.
Dewenter and Haucap (2005) have shown that larger providers choose lower termination rates than smaller competitors. As this aspect was not explicitly modelled no proposition could be derived from the theoretical model without further assumptions.
With a higher population concentration less infrastructure must be installed. Thus, maintenance costs and also costs for keeping the network running are expected to be lower which should be reflected in a lower termination rate.
Regulation effects are expected to be positive with regard to termination rates because of the competition-inducing intention of regulation. Regulation is necessary where prices are not at a competitive level. Thus, in countries where regulation is existent higher prices should be in place which have to be brought down to a competitive level. The coefficients of regulation dummies should therefore not be interpreted as the effect of regulation on termination rates but as coefficients of control variables due to the pooled estimation setup.

5 Estimation Approaches, Results and Discussion

I estimate the equation systems provided in section 4.1 using two alternative estimation methods as only very little experience in estimating mobile competition models is currently available from the literature. In doing so I try to provide some more insight into alternative methods which fit the structure typically assumed in theoretical models.

The first approach is standard generally least squares with heteroscedasticity robust standard errors. I estimate incoming traffic and termination rates separately thus ignoring any endogeneity of termination rates on incoming traffic. The alternative method is a simultaneous estimation approach (3SLS) where the term $log(termination\ rate)$ is assumed to be endogenous. In doing so this term is explained with the variables of the termination rates equation.[17]

The results of the alternative estimation approaches for own investment effects are given in table 4. First, I separately estimate the investment effects on own termination rates and MOU (columns (1) and (2)), and on competitors' termination rates and MOU (columns (3) and (4)) and afterwards combine them in one equation system (columns (5) and (6)).

By comparing the investment coefficients of the OLS estimations with those of the 3SLS estimations lower investment coefficients in the termination rate equations and higher coefficients in the traffic equations are found. The deviation of the OLS coefficients from the 3SLS coefficients for investments is driven by ignoring the endogeneity of termination rates in the traffic equation. With higher investments, first, the investor's own per-unit costs and, second, also the competitors' termination rates are affected. Ignoring the (positive) indirect effect of investments on traffic leads to a larger capex coefficient and a higher termination rate coefficient for the OLS approach.

[17]For a more technical description of the implementation of 3SLS estimation approaches see Cameron and Trivedi (2006), Cameron and Trivedi (2009).

Table 4: Estimation Results

log(term. rate)	OLS (1 a)	3SLS (2 a)	OLS (3 a)	3SLS (4 a)	OLS (5 a)	3SLS (6 a)
log(capex)	-0.025 **	-0.047 **			-0.026 *	-0.044 **
	(0.012)	(0.020)			(0.014)	(0.021)
log(weighted av. capex)			-0.042 ***	-0.066 ***	-0.035 ***	-0.061 ***
			(0.011)	(0.023)	(0.012)	(0.023)
log(market share)	-0.155 ***	-0.147 ***	-0.184 ***	-0.165 ***	-0.173 ***	-0.154 ***
	(0.014)	(0.026)	(0.015)	(0.026)	(0.015)	(0.027)
log(market size)	0.251 ***	0.196	0.186 **	0.145	0.229 **	0.192
	(0.096)	(0.170)	(0.089)	(0.170)	(0.096)	(0.171)
log(share urban pop.)	-4.679 ***	-8.860 **	-3.426 *	-7.862 *	-3.502 *	-7.574 *
	(1.678)	(4.252)	(2.067)	(4.489)	(2.050)	(4.465)
cost-based regulation	0.138 *	0.124 **	0.097	0.123 **	0.101	0.130 **
	(0.075)	(0.053)	(0.068)	(0.053)	(0.068)	(0.053)
incentive regulation	0.090 ***	0.062	0.094 ***	0.053	0.097 ***	0.057
	(0.025)	(0.042)	(0.024)	(0.043)	(0.024)	(0.043)
netmonopoly reg.	0.009	-0.037	-0.020	-0.051	-0.015	-0.048
	(0.023)	(0.045)	(0.022)	(0.047)	(0.022)	(0.047)
GSM 1800	0.103 ***	0.109 ***	0.103 ***	0.124 ***	0.094 ***	0.115 ***
	(0.018)	(0.039)	(0.017)	(0.039)	(0.017)	(0.039)
constant	-3.146 ***	--	-2.294 ***	--	-2.563 ***	--
	(0.752)	--	(0.736)	--	(0.744)	--
	country dummies included					
	year dummies included					
# Obs.	799	510	731	500	799	500
F (df)	1263.5 (28)	47046.9 (26)	1390.5 (27)	45985.5 (26)	1263.5 (28)	46401.4 (27)
"R2"	0.955	0.949	0.957	0.950	0.955	0.950

log(MOU inc.)	OLS (1 b)	3SLS (2 b)	OLS (3 b)	3SLS (4 b)	OLS (5 b)	3SLS (6 b)
log(capex)	0.009	-0.002			0.005	-0.009
	(0.008)	(0.012)			(0.008)	(0.013)
log(weighted av. capex)			0.045 ***	0.037 ***	0.053 ***	0.036 ***
			(0.012)	(0.014)	(0.009)	(0.014)
log(term. rate)	0.008	-0.203	-0.058 ***	-0.248 *	0.021	-0.271 *
	(0.015)	(0.158)	(0.022)	(0.147)	(0.017)	(0.160)
log(market share)	0.969 ***	0.937 ***	1.237 ***	0.940 ***	0.985 ***	0.940 ***
	(0.014)	(0.024)	(0.018)	(0.025)	(0.014)	(0.025)
log(market size)	0.122 **	0.137 *	-0.190 **	0.131 *	0.125 **	0.143 *
	(0.056)	(0.074)	(0.081)	(0.076)	(0.064)	(0.079)
log(share urban pop.)	-7.302 ***	-8.466 ***	-9.833 ***	-9.336 ***	-8.067 ***	-9.408 ***
	(0.920)	(1.574)	(1.380)	(1.525)	(1.064)	(1.587)
post paid	0.000 ***	0.000 ***	-0.000 **	0.000 ***	0.000 ***	0.000 ***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
cost-based regulation	-0.005	0.021	0.049 *	0.024	-0.008	0.029
	(0.018)	(0.031)	(0.026)	(0.030)	(0.020)	(0.032)
incentive regulation	0.024	0.036 **	0.081 ***	0.046 **	0.033 **	0.049 **
	(0.018)	(0.021)	(0.021)	(0.021)	(0.016)	(0.022)
netmonopoly reg.	0.060 ***	0.050 **	0.099 ***	0.062 ***	0.077 ***	0.062 ***
	(0.016)	(0.022)	(0.023)	(0.023)	(0.018)	(0.024)
constant	0.382	--	1.769	--	0.062	--
	(0.683)	--	(1.099)	--	(0.771)	--
	country dummies included					
	year dummies included					
# Obs.	510	510	500	500	500	500
F (df)	742.2 (26)	955946.2 (27)	740.9 (26)	877385.2 (27)	713.2 (27)	12659.96 (27)
"R2"	0.972	0.965	0.975	0.963	0.975	0.961

***,**,* signal the 1, 5 and 10 percent significance levels.

Std. errors are provided in brackets.

I start by focusing on the core of the theoretical study which is expressed by two hypotheses: We find a significantly negative **effect of investments on the investor's termination rate**. Dependent on the employed estimation model increasing investments by ten percentage points reduces the investor's termination rate for incoming calls by about 0.25 to 0.47 percentage points. Rearranging equation (4) the theoretical model predicts that a ten percentage points investment increase results in an increase in cost efficiency of about 0.5 to 0.94 percentage points.
Moreover, concerning the direct **impact on incoming traffic** no significant coefficients could be identified what corresponds to the results of the theoretical model. Nevertheless, investments indirectly affect traffic as at least the coefficients of the combined estimation approach in column (6b) provide evidence for a negative termination rate coefficient. I come back to this finding when calculating the effect of investments on the investor's short-run profit. So far, the estimation results confirm the first hypothesis concerning own investment effects.
With regard to the second hypothesis we observe a decrease in **termination rates** and an increase in **incoming traffic to competitors** due to investments. While the positive investment effect on traffic is in line with the outcome of the theoretical model, following theory a significantly negative effect on competitors' termination rates was only identified in line with LRIC regulation.
A more detailed analysis of alternative investment effects due to regulation schemes requires the consideration of interaction effects between investments and regulation. Table 5 provides the extension of the estimations above where I have replaced the regulation dummies by their interaction terms with investments employing the 3SLS estimation method. Columns (1) and (2) are the results where either cost-based or incentive regulation are compared to "no regulation", i.e. I exclude the other regulation scheme from the observations. In column (3) I keep both regulation schemes in the data.
We again find support for the first hypothesis on the investor's own termination rates and incoming traffic. Moreover, also the effect on incoming traffic to competitors' networks is found to be positive. Nevertheless, no evidence could be found concerning the expected outcome on competitors' termination rates. While the direct common investment effect is in the range of the previous estimations, particularly the interaction term is found to be positive and even (weakly) significant for the first approach.
Thus, the estimation results support the second hypothesis (investment externalities) with regard to the quantity of incoming traffic effect. Nevertheless, concerning the ef-

fect on termination rates the results raise the question whether regulation indeed affects MNPs' investment strategies. The theoretical model tells us that with no regulation investments should have a positive effect on competitors' termination rates due to a higher demand for incoming traffic to a monopolistic network market. Even with regulation we should either observe no investment externality on competitors' termination rates (incentive regulation, standard cost-based regulation) or a negative effect (LRIC regulation). This is why an under-investment problem is often identified in the literature with regulation uncertainty or with network competition.

As competitors reduce their termination rates in line with another provider's investments independent of the existing regulation scheme this strategy must be in the competitors' intention to make profits either in the short-run or the long-run. While I have no data on long-run investment effects I will consider the short-run effect of investments on profits in the extension below.

A number of control variables is included without developing explicit a-priori hypotheses. Hence, the discussion of their estimation results is either based on the results of other papers or which explorative in nature. We find a significant negative **market share coefficient** for termination rates which is more or less in the range of Dewenter and Haucap's findings and a positive coefficient for the traffic equations. If the market share of a provider is one percentage point higher its incoming traffic is between 0.93 percentage points (with the 3SLS approach) and about 1.24 percentage points (for the direct investment estimation using OLS) higher. Note that these high coefficients are probably mainly due to the way of constructing the dependent variable $log(MOU\ inc.)$ as this variable depends strongly on the MNP's market share. Therefore, one should not put too much weight on the $log(market\ share)$ coefficient. Similarly, a highly significant effect is found for the **share of urban population**.

In the discussion of a common regulation-investment effect I have ignored the alternative types of regulation as control variables. Regulation has an ambiguous effect on termination rates and off-net traffic: While in cost-based regulated countries termination rates are about 12.3 percentage points higher no significant effect of incentive regulation is found. Following standard textbooks like Laffont and Tirole (2000) providers have no incentive to reduce prices as such a reduction would only reduce costs but would not change the price-cost margin. In contrast, in countries with incentive regulation off-net traffic is significantly higher.

Table 5: Estimation Results including Interaction Terms

3 SLS log(term. rate)	(1 a)	(2 a)	(3 a)
log(capex)	-0.068 *	-0.021	-0.049 *
	(0.035)	(0.015)	(0.028)
log (weighted av. capex)	-0.086 **	-0.035	-0.055 *
	(0.039)	(0.016)	(0.030)
log(market share)	-0.155 ***	-0.119 ***	-0.148 ***
	(0.035)	(0.015)	(0.027)
log(market size)	0.702 ***	-0.032	0.171
	(0.270)	(0.091)	(0.171)
log(share urban pop.)	19.534 **	-14.156 ***	-8.646 *
	(9.028)	(2.292)	(4.424)
cb. reg. x log(capex)	-0.086 **		-0.074
	(0.062)		(0.053)
inc. reg. x log(capex)		-0.002	0.014
		(0.018)	(0.035)
netm. reg. x log(capex)	0.037	0.052 **	0.071
	(0.059)	(0.025)	(0.049)
cb. reg. x	0.108 *		0.079
log(weighted av. capex)	(0.061)		(0.053)
inc. reg. x		0.008	-0.002
log(weighted av. capex)		(0.018)	(0.035)
netm. reg. x	-0.048	-0.078 ***	-0.092
log(weighted av.capex)	(0.061)	(0.026)	(0.050)
GSM 1800	0.239 ***	0.109 ***	0.122 ***
	(0.066)	(0.020)	(0.039)
constant	-27.266 ***	--	--
	(9.066)	--	--
		country dummies included	
# Obs.	318	421	500
Chi2 (df)	3672.04 (26)	145092.42 (27)	46628.15 (30)
"R2"	0.920	0.988	0.951

3 SLS log(MOU inc.)	(1 b)	(2 b)	(3 b)
log(capex)	0.002	-0.007	-0.008
	(0.012)	(0.011)	(0.015)
log (weighted av. capex)	0.040 ***	0.025 **	0.034 **
	(0.014)	(0.012)	(0.016)
log(term. rate)	-0.380 ***	-0.150 ***	-0.252
	(0.130)	(0.045)	(0.156)
log(market share)	0.939 ***	0.928 ***	0.944 ***
	(0.020)	(0.018)	(0.025)
log(market size)	-0.004	0.333 ***	0.120
	(0.075)	(0.071)	(0.078)
log(share urban pop.)	-10.987 ***	-5.712 ***	-9.042 ***
	(1.767)	(2.143)	(1.582)
post paid	0.000 ***	0.000 ***	0.000 ***
	(0.000)	(0.000)	(0.000)
cb. reg. x log(capex)		-0.028	-0.020
		(0.019)	(0.027)
inc. reg. x log(capex)	-0.004		0.002
	(0.015)		(0.016)
netm. reg. x log(capex)	0.015	-0.016	0.012
	(0.021)	(0.017)	(0.025)
cb. reg. x		0.023	0.019
log(weighted av. capex)		(0.019)	(0.027)
inc. reg. x	0.014		0.007
log(weighted av. capex)	(0.015)		(0.167)
netm. reg. x	-0.007	0.016	-0.000
log(weighted av.capex)	(0.023)	(0.018)	(0.027)
constant	1.646 **	--	-0.944 *
	(0.685)	--	(1.219)
		country dummies included	
		year dummies included	
# Obs.	500	318	421
Chi2 (df)	12866.44 (30)	1050000 (28)	12571.74 (27)
"R2"	0.963	0.983	0.963

***,**,* signal the 1, 5 and 10 percent significance levels.

Std. errors are provided in brackets.

To sum up, we have analyzed the results of the theoretical model using alternative estimation approaches. We find a negative effect of investments on own termination rates and no significant effect of investments on incoming traffic which means that the first hypothesis cannot be rejected. Moreover, the estimations support the assumption in the theoretical model that investments in mobile infrastructure are mainly cost-related. With regard to the second hypothesis that investments positively affect competitors' termination rates and also increase competitors' incoming traffic the outcome is ambiguous: While competitors reduce termination rates due to other MNPs' investments their incoming traffic rises. In the following extension the empirical findings will be replaced into the wholesale profit functions and I will observe how investments affect the investor's and the competitors' wholesale profits. In doing so I particularly want to check whether competitors' termination rate reduction is profit-increasing even in the short-run.

Extension: Calculation of the Investment Effect on Profits

By adopting the estimation results to the theoretical model I calculate the effect of investments on wholesale profits. I do this exercise only for the 3SLS results due to the restrictions of the OLS approach. As the per-unit costs of call termination are very small I fix it to zero. The change in profit is independent of the underlying retail market pricing scheme meaning that the traffic dependent change in profits is identical whether we consider linear retail pricing or non-linear retail pricing.

The investor's absolute change in profits from incoming calls due to investments is given by equation (5). Rewriting this equation yields:

$$\frac{\partial \pi^i_{j,i}}{\partial k_i} = \frac{\partial (t_i - c_i)}{\partial k_i} \sum_j q_{j,i} + (t_i - c_i) \frac{\partial \sum_j q_{j,i}}{\partial k_i} \tag{16}$$

Dividing (16) by profits per investment yields the relative profit change:

$$\frac{\partial \pi^i_{j,i}}{\partial k_i} \frac{k_i}{\pi^i_{j,i}} = \frac{\partial (t_i - c_i)}{\partial k_i} \frac{k_i}{t_i} + \frac{\partial \sum_j q_{j,i}}{\partial k_i} \frac{k_i}{\sum_j q_{j,i}} \tag{17}$$

In table 4 both coefficients β^{q1}_{inv} and β^{q1}_{t} are not significantly different from zero in the traffic equation whereas β^{q1}_{inv} is weakly significant in table 5. Note that the quantity change is the sum of the cost-related quantity change and the termination rate-related quantity change. Moreover, we know from the derivative of own termination rates to investments that the change in termination rates is half the change in per-unit costs. Thus, equation (17) changes to:

$$\begin{aligned}\frac{\partial \pi^i_{j,i}}{\partial k_i}\frac{k_i}{\pi^i_{j,i}} &= -\frac{\partial t_i}{\partial k_i}\frac{k_i}{t_i} + \frac{\partial \sum_j q_{j,i}}{\partial t_i}\frac{t_i}{\sum_j q_{j,i}}\frac{\partial t_i}{\partial k_i}\frac{k_i}{t_i} \\ &= -\beta^{t1}_{inv} + \beta^{q1}_{t1}\beta^{t1}_{inv}\end{aligned} \tag{18}$$

Similarly, one has to add the significant regulation coefficients of table 5 for the investment effect on own profits.[18] Doubling investments increases short-run profits from incoming traffic by about 4.7 to 6.8 percentage points (when including interaction terms). Similarly, the relative investment externality on competitors' profits is calculated. The relative profit change due to a one-percent change in investments is given by:

$$\frac{\partial \sum_{-j} \pi^j_{-j,j}}{\partial k_i}\frac{k_i}{\sum_{-j} \pi^j_{-j,j}} = \frac{\partial t_j}{\partial k_i}\frac{k_i}{t_j} + \frac{\partial \sum_{-j} q_{-j,j}}{\partial k_i}\frac{k_i}{\sum_{-j} q_{-j,j}} \tag{19}$$

Rewriting equation (19) yields:

$$\begin{aligned}\frac{\partial \sum_{-j} \pi^j_{-j,j}}{\partial k_i}\frac{k_i}{\sum_{-j} \pi^j_{-j,j}} &= \frac{\partial t_j}{\partial k_i}\frac{k_i}{t_j} + \frac{\partial \sum_{-j} q_{-j,j}}{\partial c_i}c_i'(k_i)\frac{k_i}{\sum_{-j} q_{-j,j}} + \frac{\partial \sum_{-j} q_{-j,j}}{\partial t_j}\frac{t_j}{\sum_{-j} q_{-j,j}}\frac{\partial t_j}{\partial k_i}\frac{k_i}{t_j} \\ &= \beta^{t2}_{inv} + \beta^{q2}_{inv} + \beta^{q2}_{t}\beta^{t2}_{inv}\end{aligned} \tag{20}$$

By replacing the coefficients with the estimation results in tables 4 and 5 we find that the competitors' wholesale profit changes by -1.2 and -2 percentage points, respectively. While there exists a strong impact of investments on termination rates and also on traffic the impact on profits is close to nil. In contrast to no investment effect on the investor's own incoming traffic the increase in incoming traffic to competitors is relatively large and, thus, reduces the negative effect on wholesale prices in the competitors' profit function. Thus, at least in the short-run the effect on incoming traffic cannot outweigh the reduction in termination rates.

The question still remains why competitors reduce termination rates if they are not obliged to do so. One admittedly speculative consideration might be the following: The players in a market know the competition-driving variables of the market which are in particular prices (on the retail and the wholesale level) and traffic. Moreover, as they are

[18] I only consider the common estimation approach in columns (3) as this is the correspondent estimation approach to table 4.

in a repeated game, they have experience in the impact of investments on these variables, they know their competitors and, due to legal obligations and sunk investment costs, they know that their competitors will remain the same in the future. Since an investor is able to extract higher rents due to its current market share and its customers' calling behavior (without gaining market shares in the short-run) and since competitors lose only little by reducing termination rates we probably observe a tit-for-tat game among the MNPs. Therefore, providers refrain from increasing their wholesale prices expecting competitors to do the same. Additionally, taking into account multi-market activities providers probably compete tougher where it is more profitable and spare themselves where they gain less.

In a nutshell, the consideration of wholesale profits provides more insight into the change in the wholesale price-cost margin and the change in quantities due to investments. By adopting the estimation results to the theoretical model we find a positive own-profit effect as investments increase the investor's wholesale price-cost margin and the incoming traffic. On the other hand we cannot identify a positive effect on competitors' profits. Moreover, the investment effect on competitors' profits is close to zero as the (direct and the indirect) investment effect on traffic compensates for the termination rate reduction.

6 Concluding Remarks and Limitations

Investments in competing networks is an ongoing issue in network-based markets because of mainly two reasons: First, investments are implemented to increase the investor's market share and, thus, particularly revenue. Nevertheless, the service provided depends on the users what means that a provider is ceteris paribus attractive only because of a larger customer base. Second, investments directly affect the traffic to competitors' networks. On the one hand (retail and wholesale) prices are altered and on the other hand off-net traffic changes. In this paper I wanted to provide more insight into these two aspects of investments in mobile infrastructure under the alternative European regulation schemes.

Starting with a theoretical model, I show that under a linear pricing scheme investments should increase both own and competitors' short-run wholesale profits from traffic between the investor and any competitor. I extend the analysis to non-linear retail pricing and find mainly similar results. Afterwards, I compare the outcomes to the usual cost-based and incentive regulation approaches known from the literature: While own termination rates decrease in line with investments, competitors' termination rates should either increase (in the absence of regulation), remain unaffected (with incentive regulation and standard cost-based regulation) or decrease (with LRIC regulation). Concerning traffic, both traffic to the investor and from the investor increases.

These findings are tested employing data for European mobile markets. With regard to own investment effects I indeed find support for a termination rate reduction. Moreover, with lower termination rates also the amount of incoming traffic to the investor's network is increased. By replacing the empirical findings into the theoretical model one gets the effect of investments on the investor's wholesale profits which raises by about 4.7 to 6.7 percentage points due to doubling investments.

Concerning the effect on competitors' profits, I find that the amount of incoming traffic also increases, whereas termination rates decrease (as expected only in line with LRIC regulation). I therefore replace the regulation parameters in the estimation equations by their interaction terms with investments. In doing so I find only a weak, mostly insignificant, additional effect on termination rates.

Since regulation is found to have only a minor impact on the investment effect on termination rates and off-net traffic it is concluded that the findings are probably due to competitors' strategic reaction. Combining the empirical findings with the theoretical model we get the following results: While the impact of investments on competitors' termination rates and traffic is not negligible only a small investment externality on competitors' profits could be identified. In particular, the direct investment effect on incoming traffic compensates for the reduction in termination rates in the competitors' profit function.

These findings raise the question whether MNPs probably behave as in a tit-for-tat game: While a competitor loses only little in the short-run the investor is able to get a positive return on its investments from incoming traffic and, in particular, also from its own customers (because of a higher retail price-cost margin and more outgoing traffic). As all MNPs invest continuously each of them gains from the others' reluctance.[19]

Note that the analysis is based on some central limitations which are mainly due to the challenge with data availability: First, I have only considered the short-term effect of investments on termination rates and off-net traffic. In doing so I particularly ignore investment costs and their depreciation over time which also enter the per-unit costs.

[19]Strategic interaction in mobile termination markets has been analyzed in Höffler (2007).

Nevertheless, one could easily correct the per-unit costs in the theoretical model but the central results will remain unchanged. Second, I have assumed market shares to be constant. A more comprehensive estimation approach should take into account the time dependence. Due to lags in the data set I refrain from such an approach and only control for time effects. Finally, more detailed cost information would strongly improve the analysis of the price-cost margin and, thus, the analysis of off-net profits.

Even with these limitations the findings provide more insight into the strategic interplay between MNPs in line with regulation and investments. Concerning the recommendation by the European Commission of May 2009 that LRIC regulation should be implemented in the market for wholesale voice call termination (Market 16) in all member states I find that the type of regulation has only a minor impact on investment effects.

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Appendix

A.1 The Indirect Investment Effect

The own investment effect and the investment externality are the investment effects usually analyzed in the literature. For example Vareda (2007) compares quality-increasing and cost-reducing investments if unbundling is mandatory and if it is not. Valletti and Cambini (2005) analyze investments with two competing networks and show that cost-based regulation reduces the incentive to invest. As in the literature on network investments mainly two competing networks are considered, the indirect investment effect is ignored.[20] An indirect investment effect stems from the investment of one MNP on the traffic between two other MNPs. By reducing its per-unit costs the outgoing traffic from the investor is increased. As termination rates (at least partially) depend on the average incoming calls from all MNPs, i's investments affect all competitors' termination rates for incoming calls. With prices dependent on termination rates outgoing calls are affected by any provider's investments. In less concentrated markets a lower indirect investment effect should be observed. In contrast, with one large MNP and a number of smaller providers we expect a strong indirect investment effect from the larger one to the others whereas the indirect investment effect should be lower for investments of smaller MNPs.

With termination regulation the indirect investment effect disappears as all forms of price regulation ignore traffic and, thus, the influences from investments.

The profit stemming from j's incoming calls from any MNP $-j \neq i$ is given by $\sum_{-j\neq i} \pi^{j}_{-j,j}$ $= (t_j - c_j)s_j \sum_{-j\neq i} s_{-j}(a - b_{-j}p_{-j,j})$. Although i is not involved in the interconnection between j and any competitor $-j \neq i$, as we know from (6), i's investment in cost-reduction affects j's termination rate . The increase in wholesale prices is passed on to $-j$'s off-net prices altering $-j$'s outgoing traffic. Deriving j's wholesale profit with respect to k_i yields:

$$\frac{\partial \sum_{-j\neq i} \pi^{j}_{-j,j}}{\partial k_i} = -c_i'(k_i)\frac{s_i b_i}{4\sum_{-j} s_{-j}b_{-j}} s_j \sum_{-j} s_{-j}\left(a - b_{-j}\left(c_{-j} + \frac{c_j}{2}\right)\right.$$

$$\left. + \frac{\sum_{-j} s_{-j}(a - b_{-j}c_{-j})}{4\sum_{-j} s_{-j}b_{-j}}\right) + c_i'(k_i)(t_j - c_j)s_j \sum_{-j} s_{-j}b_{-j}\frac{s_i b_i}{4\sum_{-j} s_{-j}b_{-j}} \quad (21)$$

$$= -c_i'(k_i)\frac{s_i b_i}{4\sum_{-j\neq i} s_{-j}b_{-j}} s_j \sum_{-j} s_{-j}\left((a - b_{-j}c_{-j}) - b_{-j}\frac{\sum_{-j} s_{-j}(a - b_{-j}c_{-j})}{\sum_{-j} s_{-j}b_{-j}}\right)$$

[20] We discuss this effect only in the theoretical part for reasons of completeness as we cannot single it out with our data set.

With regard to incoming calls there is a positive effect on the mark-up of termination rates over per-unit costs as termination rates increase due to i's investments while termination costs remain unaffected by i's investments. Nevertheless, total calling minutes are reduced as competitors' off-net prices increase in j's termination rates. Taking a look at the terms in large brackets it is unclear whether the individual demand term exceeds the average or not. With $c_{-j} = c$ we find for b_{-j} small, i.e. for calls from smaller providers terminating on network j, that the expression in brackets is positive. To sum up, the effect of i's cost-reducing investment on profits from incoming calls from other providers to a provider j is ambiguous. While the wholesale price effect is positive due to the demand increase from network i, the total demand effect from the other networks is negative. Thus, without further assumptions on the demand functions no distinct proposition concerning the indirect investment effect could be derived.

A.2 Calculation of the investment effect on own and competitors' termination rates

In contrast to the linear pricing situation we fix per-unit prices at per-unit costs, $p_{j,i} = c_j + t_i$, and get for i's profit from incoming calls:

$$\begin{aligned} \pi^i_{j,i} &= s_i \textstyle\sum_j s_j(t_i - c_i)(a - b_j p_{j,i}) \\ &= s_i \textstyle\sum_j s_j(t_i - c_i)(a - b_j(c_j + t_i)) \end{aligned} \tag{22}$$

Deriving (22) with respect to t_i yields:

$$t_i = \frac{\sum_j (a - b_j c_j)}{2\sum_j s_j b_j} + \frac{c_i}{2} \tag{23}$$

Deriving t_i with respect to investments yields:

$$\frac{\partial t_i}{\partial k_i} = \frac{c_i'(k_i)}{2} \tag{24}$$

Similarly, we get for the competitors' termination rates change due to i's investments:

$$t_j = \frac{\sum_{-j} (a - b_{-j} c_{-j})}{2\sum_{-j} s_{-j} b_{-j}} + \frac{c_j}{2} \tag{25}$$

$$\frac{\partial t_j}{\partial k_i} = -c_i'(k_i)\frac{s_i b_i}{2\sum_{-j} s_{-j} b_{-j}} \tag{26}$$

A.3 Investment effect on outgoing traffic

Let us first derive the **change in the investor's profits from outgoing traffic due to a change in investments**. Deriving $\sum_j \pi^i_{i,j}$ with respect to k_i yields:

$$\frac{\partial \sum_j \pi^i_{i,j}}{\partial k_i} = -c_i'(k_i)\frac{s_i}{2}\sum_j \left(s_j(a - b_i(c_i + t_j)) \left(1 - \frac{s_i b_i}{2\sum_{-j} s_{-j} b_{-j}} \right) \right) > 0 \qquad (27)$$

With $i \in \{-j\}$ the last term is non-negative. By increasing efficiency profits from outgoing calls also increase.
For s_i close to 0 or close to 1 the investment effect on outgoing minutes is smaller which causes an inverted u-shaped relationship for the investment effect dependent on the own market share. Both if the investor is comparably small and if the investor is comparably large a lower number of calls originate from the investor's network.
In a nutshell, two effects on the investor's profits exist: As the absolute investment effect on retail prices for outgoing calls is only half the absolute investment effect on origination costs and termination rates the per-unit mark-up for outgoing calls increases. Additionally, by reducing off-net prices customers are more willing to call customers in competitive networks.

Next we derive the **effect of investments on the competitors' profits from outgoing traffic to the investor**: We know from (4) that i's investment reduces its termination rate. Furthermore, we know from 2 that j's off-net retail price for calls to i is reduced only to half the extent as the reduction in termination rates. Thus, not only i's per-unit mark-up for outgoing calls to j but also j's per-unit mark-up for outgoing calls to i increases as the change in i's off-net price is lower than the termination rate change. By reducing off-net prices the call length for outgoing calls to network i increases in total raising j's profits for outgoing calls to i:

$$\frac{\partial \pi^j_{j,i}}{\partial k_i} = -\frac{c_i'(k_i)}{2} s_i s_j (a - b_j(c_j + t_i)) > 0 \qquad (28)$$

Finally, let us derive the **investment effect on profits from outgoing traffic to competitors' which are not the investor**. j's profits from outgoing calls to any other providers $-j \neq i$ are given by $\sum_{-j} \pi^j_{j,-j} = \sum_{-j}(p_j - t_{-j} - c_j)s_j s_{-j}(a - b_j p_{j,-j})$.

Deriving this sum with respect to k_i yields:

$$\begin{aligned}\frac{\partial \sum_{-j} \pi^j_{j,-j}}{\partial k_i} = {} & c_i'(k_i)\frac{s_j}{2}\sum_{-j} s_{-j}\frac{s_i b_i}{4\sum_{--j} s_{--j}b_{--j}}\Bigg(a - b_j c_j - b_j \frac{c_{-j}}{2} \\ & - b_j \frac{\sum_{--j} s_{--j}(a - b_{--j}c_{--j})}{2\sum_{--j} s_{--j}b_{--j}}\Bigg) + c_i'(k_i)\frac{s_j}{2}\sum_{-j} s_{-j}\Bigg(a - c_j - \frac{c_{-j}}{2} \\ & - \frac{\sum_{--j} s_{--j}(a - b_{--j}c_{--j})}{2\sum_{--j} s_{--j}b_{--j}}\Bigg) b_j \frac{s_i b_i}{4\sum_{--j} s_{--j}b_{--j}} \\ = {} & c_i'(k_i)\frac{s_j}{2}\sum_{-j} s_{-j}\Bigg(a - b_j c_j - b_j \frac{c_{-j}}{2} \\ & - b_j \frac{\sum_{--j} s_{--j}(a - b_{--j}c_{--j})}{2\sum_{--j} s_{--j}b_{--j}}\Bigg)\frac{s_i b_i}{4\sum_{--j} s_{--j}b_{--j}} < 0 \end{aligned} \tag{29}$$

Profits from outgoing calls are reduced as retail prices for outgoing calls to competitors' networks increase with the competitors' termination rates. Additionally, also the per-unit price-cost margin is reduced as the absolute increase in retail prices is lower than the absolute increase in termination rates. Therefore, we find a negative indirect effect of i's investments on j's profits from outgoing calls.

A.4 Data Selection and Data Adjustments

We employ data from multiple sources including information about the fully vertically integrated MNPs in the EU 15 as well as Norway and Switzerland, data about termination regulation and the termination rates, information about individual transmission technology per provider and data about population concentration.

Financial information and customer information per MNP are taken from the Merrill Lynch European Wireless Matrix 2006 and 2007. Merrill Lynch offers detailed information for each provider including traffic and financial information on a national level on a quarterly basis. From this data set we have selected information on calling minutes, market shares in terms of customers, the total market size and information about investments. As a proxy for investments we use capital expenditures (capex) having in mind that capex also includes investment in assets which are not directly linked to network infrastructure, like buildings. Nevertheless, investments in assets which are not related to physical network infrastructure are expected to be only a minor share of the total capex.

Termination rates are taken from the Ovum data base. Ovum provides termination rate information for each MNP. Note that at least for 2001 we have to adjust termination rates due to the introduction of the Euro in most countries of our sample. For most of the MNPs Ovum provides on-peak and off-peak prices and traffic-dependent average

termination rates which we use for the analysis.
Information about the alternative regulation schemes is taken from the Plaut Economics Regulatory Index for the years 2000 until 2006 and complemented for 2007 with data from national regulators' websites. The Plaut index is based on a questionnaire for EU member states. We selected the questions concerning mobile interconnection regulation and transformed the disaggregated values for each country and each year into dummy-variables for alternative regulation mechanisms and asymmetric regulation taking into account country information provided on the regulators' websites. We complemented the information also for Norway and Switzerland since they are not EU member states and, thus, are not covered by the index.
The transmission technology is a main driver of per-unit costs. In Europe mainly two frequency bands are allowed for mobile communication which are a frequency band around 900 MHz and a frequency band around 1800 MHz. Information about the licenses of each MNP for the two frequency bands is taken from the GSMA website (www.gsmworld.com). GSMA is the worldwide association of mobile companies. On the website an overview of licenses for transmission technologies is offered including information about the year of the grant of a license. It is necessary to distinguish between the two frequency bands as the transmission in the higher-frequency band leads to higher transmission costs. This should be reflected in the per-unit costs and thus also in the termination rates.
In network-based markets customer concentration is a key driver of costs as in more densely populated areas since the infrastructure could be installed at lower costs. With mobile infrastructure two ambiguous effects might exist as country coverage has been one of the key issues from the political perspective. Companies were forced to build up a network infrastructure which not only covers most of the population but also most of the area. On the other hand, in more densely populated areas, where the population coverage is expected to be easier, congestion is an issue. This is the case since communication of more customers in one cell around a transmission tower reduces the speed of transmission, thus, impairing the communication quality. We use data for population concentration from the OECD since standard density measures assume a uniform distribution of the population.

We know from the note on data challenges in the Merrill Lynch report that off-net minutes are double-counted. With the assumption that traffic is market share-dependent we know the following relation between the Merrill Lynch data and the actual values:

$$\widehat{MOU}_i = s_i \sum_j MOU_j + MOU_i \tag{30}$$

where $\widehat{MOU}_i$ are the MOUs of MNP i as given in the Merrill Lynch report and MOU_i are the unobserved (actual) MOUs of MNP i. Rewriting this term in matrix notation to get the relation of the given MOUs and the corrected MOUs for all providers we achieve the following equation:[21]

$$\widehat{\mathbf{MOU}} = (\mathbf{I} + \mathbf{s}\mathbf{1}_{1\times n} - diag(\mathbf{s}))\mathbf{MOU} \tag{31}$$

where $\widehat{\mathbf{MOU}}$, $\mathbf{MOU}$ and $\mathbf{s}$ are $(n \times 1)$ vectors, $\mathbf{I}$ is the $(n \times n)$ identity matrix, $diag(\mathbf{s})$ is the $(n \times n)$ diagonal matrix of $\mathbf{s}$ and $\mathbf{1}_{1\times n}$ is a ones-vector. With $s_i \leq 1$ for each element in $\mathbf{s}$ we know that the term in brackets is positive definite. Rearranging terms yields:

$$\mathbf{MOU} = (\mathbf{I} + \mathbf{s}\mathbf{1}_{1\times n} - diag(\mathbf{s}))^{-1}\widehat{\mathbf{MOU}} \tag{32}$$

$\mathbf{MOU}$ is the vector of the adjusted MOUs for all MNPs in country l at time z.
Note that data for smaller firms are at least partially based on Merrill Lynch estimations. Thus, it might be the case that dependent on the estimation data for smaller MNPs there is a lower statistical variance over time or also cross-sectional dependence on the estimation methodology used for getting information about these MNPs.

A.5 Calculation of actual MOUs

The relation between the given MOUs of MNP i and the actual MOUs is given as follows:

$$\widehat{MOU}_i = s_i \sum_j MOU_j + MOU_i \tag{33}$$

For any MNP i the MOUs given in the Merrill Lynch European wireless matrix are its actual MOUs plus the incoming MOUs from all other providers. Thus, for all providers the relationship is the following:

$$\begin{array}{llll} \widehat{MOU}_1 = 1 & MOU_1 + s_1 & MOU_2 + s_1 & MOU_3 + ... \\ \widehat{MOU}_2 = s_2 & MOU_1 + 1 & MOU_2 + s_2 & MOU_3 + ... \\ \widehat{MOU}_3 = s_3 & MOU_1 + s_3 & MOU_2 + 1 & MOU_3 + ... \end{array} \tag{34}$$

We can rewrite this equation system in matrix notation as follows:

$$\begin{array}{ll} \widehat{\mathbf{MOU}} & = \mathbf{s}_{mat}\mathbf{MOU} \\ \begin{pmatrix} \widehat{MOU}_1 \\ \widehat{MOU}_2 \\ \widehat{MOU}_3 \\ ... \end{pmatrix} & = \begin{pmatrix} 1 & s_1 & s_1 & ... \\ s_2 & 1 & s_2 & ... \\ s_3 & s_3 & 1 & ... \\ ... & & & \end{pmatrix} \begin{pmatrix} MOU_1 \\ MOU_2 \\ MOU_3 \\ ... \end{pmatrix} \end{array} \tag{35}$$

[21] How one gets from (30) to (31) is shown in the next subsection.

Rearranging $\mathbf{s}_{mat}$ yields:

$$\begin{aligned}\mathbf{s}_{mat} &= \begin{pmatrix} 1 & s_1 & s_1 & ... \\ s_2 & 1 & s_2 & ... \\ s_3 & s_3 & 1 & ... \\ ... \end{pmatrix} \\ &= \begin{pmatrix} s_1 \\ s_2 \\ s_3 \\ ... \end{pmatrix} (1; 1; 1; ...) + \begin{pmatrix} 1 & 0 & 0 & ... \\ 0 & 1 & 0 & ... \\ 0 & 0 & 1 & ... \\ ... \end{pmatrix} - \begin{pmatrix} s_1 & 0 & 0 & ... \\ 0 & s_2 & 0 & ... \\ 0 & 0 & s_3 & ... \\ ... \end{pmatrix} \\ &= \mathbf{s1}_{1\times n} + \mathbf{I} - diag(\mathbf{s})\end{aligned} \tag{36}$$