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Network Competition: Empirical Evidence on Mobile Termination Rates and Profitability

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Abstract

We analyze a model of multi firm competition between mobile network operators. The model assumes inelastic usage demand and full penetration, and allows for asymmetric termination rates, differences in marginal costs and vertical differentiation. A key property is that operators' equilibrium profit is unaffected by an identical change in all termination rates in the market - we call this the profit neutrality hypothesis. The model is well suited for econometric implementation. We use a panel data set comprising north western European mobile operators to estimate equilibrium profit functions and find that we cannot reject the profit neutrality hypothesis. The results suggest that a reduction in mobile termination rate levels in mature markets will not necessarily benefit consumers.

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1. Introduction

When a mobile subscriber calls a subscriber on another mobile network, the originating network operator pays a fee per minute to the terminating operator. These fees, denoted *Mobile Termination Rates (MTRs)* are frequently regulated. The national regulatory authorities in the EU member states consider mobile operators as de-facto monopolists in the wholesale voice termination market. The operators are therefore subject to ex ante regulation in this market irrespective of the competitive pressure in the retail market. The levels of mobile termination rates vary substantially between states in the EU and are frequently asymmetric within each state.[1] The European Commission, and the national regulators, wants to reduce and harmonize mobile termination rates across member states and within each state, see European Commission (2008) and European Regulatory Group (2007).

Policy makers, notably Viviane Reding, the EU's Telecoms Commissioner, expect a reduction in termination rates to benefit consumers.[2] However, the economic literature, which we briefly review below, is inconclusive on the welfare effects of such a reduction as well as the distributional effect on consumer surplus and profits.

This paper presents empirical evidence on the effect of mobile termination rates on operator profits. We use a panel data set comprising a subset of European mobile operators. We find that profits increase in the operator’s own termination rate and decrease in the average level of competing operators’ termination rates. Moreover, we cannot reject that profits are unaffected by an identical change in all mobile termination rates. Thus, our results support the claim that profits in the mobile industry are unaffected by the level of mobile termination rates.

The seminal papers by Armstrong (1998) and Laffont, Rey and Tirole [1998a, 1998b] provide a general framework to assess the outcomes of competition between interconnected network operators. In this literature competition is modelled as a two-

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[1] The European Regulators Group (ERG) carries out MTR benchmark studies. According to the European Regulatory Group (2007), the MTR benchmark study in January 2007 identified 25 countries that allow asymmetric MTRs and 6 countries where the regulator imposes symmetric rates.
[2] EUROPA Press Releases. Reference: IP/07/1333 Date: 14/09/2007

stage game. In the first stage the termination rate of each network is determined, and in the second stage the networks compete in attracting customers. The principal question is whether the networks, in an unregulated economy, can use the termination rates as a collusive device to soften competition in the second stage. In particular, the case studied is that of a symmetric duopoly where the two firms agree on reciprocal (symmetric) termination rates. A major insight is that the effect of changes in the symmetric termination rate on the networks' profits depends on the call-plans offered to consumers. With the above move order, this effect is unaffected by whether the symmetric charge is negotiated by the firms, or set by regulatory authorities. Armstrong (2002) and Jullien and Rey (2008) provide excellent reviews of the literature building on the above cited papers. Focusing on calling party pay regimes, the main results on the effects of changes in reciprocal termination rates on profits in symmetric, full participation duopoly can be summarized as follows[3] [4]:

- Armstrong (1998) and Laffont, Rey and Tirole (1998a) study the case with linear pricing and no discrimination based on whether the call terminates on-net or off-net. They find that an increase in a symmetric termination rate *increases* profits. In this case the networks can use a high termination rate as an instrument to soften competition at the second stage by raising each other's marginal cost.

- Laffont, Rey and Tirole (1998a) demonstrate that the profit raising effect disappears when the networks compete in two-part tariffs with no network based discrimination at the second stage. Profits are in this case *independent* of the termination rate. The increase in profits from incoming off-net traffic following an increase in the termination rate is exactly matched by the profit loss due to the induced decrease in the fixed fee. Dessein (2003) and Hahn (2004) extend the basic model to allow for customer heterogeneity. They find that the profit neutrality result still holds when the networks compete in menus of non-linear tariffs as long as all customer groups participate in equilibrium.

[3] Asymmetric duopoly with two part tariffs has been investigated by Carter and Wright (2003), de Bijl and Peitz (2002) and Peitz [2005a, 2005b].
[4] Calzeda and Valletti (2008) and Jeon and Hurkens (2008) consider models with more than two firms. However, these papers focus on symmetric firms.

- Laffont, Rey and Tirole (1998b) and Gans and King (2001) consider the case of network based discrimination.[5] Gans and King (2001) show that when the networks compete in two-part tariffs with network based discrimination an increase in the termination rate *decreases* profits. The mechanism is that the competing networks have an incentive to negotiate a termination rate below marginal costs because this softens competition for market shares at the second stage.[6] The effects of an increase in the termination rate when the networks compete in linear prices with network based discrimination are ambiguous. Laffont, Rey and Tirole (1998b) find that profits increase when the networks are not too close substitutes, while the effect is ambiguous otherwise.

It is not easy to draw on these results to predict the effects on profits (or welfare) of a reduction in mobile termination rates as put forward by The European Commission. Firstly, the results are derived in symmetric duopoly. All European states have more than two operators which are frequently highly asymmetric in terms of market shares and termination rates. It is a reasonable conjecture that the theoretical results referred to above could be generalised to symmetric, multi-firm competition, but not to asymmetric market structures. Secondly, most European mobile operators offer a menu of call plans that include all of the tariffs discussed above. Consequently, it is hard to assess which tariff dominates the competitive situation.

Building on Armstrong (2002) we develop a theoretical model of competition between two or more, potentially asymmetric, interconnected networks. A key modelling assumption is that usage is inelastic. This simplifying assumption enables us to derive a simple closed form solution for equilibrium profits. We show that an identical change in all termination rates does not affect profits. Thus, similar to the models where networks compete in two-part tariffs with no network based discrimination, the current model exhibits a form of profit neutrality.

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[5] Network based discrimination exists when the on-net minute price differs from the off-net minute price. An on-net (off-net) call is a call originated on one network and terminated at the same (another) network.
[6] In line with this the authors argue that bill-and-keep may be a form of tacit collusion.

We estimate the model using a panel dataset on firm specific mobile termination rates and profits comprising 26 mobile operators in 9 European countries in the period 2003-2006. The econometric model performs very well with significant parameters of expected signs. The main result is that we cannot reject the profit neutrality hypothesis, i.e. that profits are unaffected by an identical change in all mobile termination rates.

The rest of the paper is organised as follows: In section 2 we develop the theoretical model of competition between asymmetric networks. In section 3 we describe the data and present the econometric specification. In section 4 we present and discuss the estimation results. Finally, we offer some concluding remarks in section 5.

2. Multi-firm competition

The final objective of this section is to derive a closed form equilibrium profit function, i.e. profit as a function of termination rates, suitable for econometric implementation on firm data from European mobile markets. This involves the following major challenges: Firstly, most markets include more than two firms. The firms vary in size and possibly marginal costs, and are frequently subject to different termination rates. Secondly, most mobile firms offer a menu of call plans that include all the tariffs reviewed in the previous section.[7]

There are no models that can cope with these issues simultaneously in a tractable way. Clearly, some powerful simplifying assumptions are necessary. The approach taken here is to generalize the unit demand, asymmetric duopoly model in Armstrong (2002) to N firms[8]. As shown below this generalisation has a simple closed form solution for equilibrium profits.

[7] There is limited public information on the distribution of customers and profits on different call plans. In their quarterly reports, most operators split the figures on the number of customers, traffic revenues and minutes in the categories 1) Prepaid and 2) Subscription. The former category resembles linear tariffs, while the second category comprises various forms of non-linear tariffs including the two-part tariffs discussed in the literature. However both the linear and non-linear tariffs frequently include call plans with and without network based discrimination. Hence, it is hard to put the special cases discussed in the literature to an empirical test.

[8] Section 4.2.4 in Armstrong (2002)

The model

Assume that subscribers' demand for calls is inelastic, i.e. independent of the calling price, and that the calling pattern is balanced, i.e. that all customers, irrespective of which network they subscribe to, are equally likely to receive a call. As a normalisation, each subscriber makes exactly one call in the time period under consideration (this normalisation is relaxed in the empirical implementation). Finally, we assume that the market is fully covered i.e., $\sum_{i=1}^{N} x_i = X$, where x_i is the number of customers of firm *i*, X is the total number of potential customers, and the market share of firm *i*, $s_i = x_i / X$.

These assumptions are basically equal to those in the asymmetric duopoly model in Armstrong (2002).

Given the unit demand, the mobile networks compete for customers in a single price p_i. One interpretation is that the networks compete in 'total charges' for making the exogenous number of calls[9].

There are $N \geq 2$ interconnected mobile firms in the economy (the national market). Without loss of generality, we assume zero fixed costs per subscriber and that the marginal cost of originating a call is equal to the marginal cost of terminating a call. These marginal costs can vary between firms, such that, for network *i*, an on-net call consists of origination and termination costs, $2c_i$. Let a_i denote the termination rate network *i* receives per incoming call. A call from network *i* to network *j* thus has perceived marginal costs $c_i + a_j$, and the (wholesale) margin on an incoming call is $a_i - c_i$.

Profit for firm *i* is then given by

[9] The present model also closely resembles section 6.3 in de Bijl and Peitz (2002) where the networks compete in 'flat-rate' tariffs, i.e. a subscription fee and a zero charge for calls. Such tariffs exist in some markets, but are not widespread. A related, very frequently offered tariff is that of 'included minutes' – a tariff with a subscription fee, an included number of minutes at a zero charge, followed by a positive marginal charge. This kind of three-part tariff has however, to our knowledge, not been analysed in the context of interconnected networks, see Grubb (2007) for a general analysis without interconnection.

$$\pi_i = \underbrace{s_i X\left(p_i - s_i 2c_i - \sum\nolimits_{j \neq i} s_j \left(c_i + a_j\right)\right)}_{\text{Retail profits}} + \underbrace{s_i X \sum\nolimits_{j \neq i} s_j \left(a_i - c_i\right)}_{\text{Wholesale profits}}.$$

Using the full market cover assumption this profit expression can be simplified to

$$\pi_i = s_i X\left(p_i - 2c_i + \sum\nolimits_{j \neq i} s_j \left(a_i - a_j\right)\right). \qquad 1)$$

The market shares entering the profit expression are functions of the vector of prices, $\mathbf{p} = \{p_1, p_2, ..., p_N\}$, and, in the present case, a vector of exogenous or predetermined firm specific characteristics, $\mathbf{u} = \{u_1, u_2, ..., u_N\}$,

$$s_i = s(\mathbf{p}, \mathbf{u}), \quad \frac{\partial s_i}{\partial p_i} < 0. \qquad 2)$$

Normally we would consider situations where all products are substitutes, but Proposition 1 below also holds in the case where $\partial s_i / \partial p_j < 0$ for some pairs of *i* and *j*. The vector of firm specific characteristics, $\mathbf{u}$, is a parameterization that allows asymmetric market shares even if all prices are equal.

The game proceeds in the usual fashion: At stage 1 the firms' termination rates, $a_1, a_2, ..., a_N$ are determined, for instance set by the regulatory authority; at stage 2 the firms compete one-shot in prices.

If we differentiate 1) with respect to price and rearrange, we can write the first-order condition for firm *i*, $i = 1, 2, ..., N$, as:

$$p_i = 2c_i - \sum\nolimits_{j \neq i} s_j \left(a_i - a_j\right) - s_i \left(\frac{\partial s_i}{\partial p_i}\right)^{-1} \left(1 + \sum\nolimits_{j \neq i} \frac{\partial s_j}{\partial p_i} \left(a_i - a_j\right)\right). \qquad 3)$$

The solution of the *N* first-order conditions gives a candidate equilibrium. In general, an interior equilibrium will exist if conditions are not 'too asymmetric', and if the firms' products are not 'too close substitutes'.[10] The interior equilibrium is a price vector

[10] With "Hotelling style" market share functions, the interior equilibrium is unique, see the next section.

$\mathbf{p}^* = \{p_1^*, p_2^*,..., p_N^*\}$ that satisfies the first-order conditions such that $\sum s_i^* = 1,\ s_i^* \in \langle 0,1 \rangle$ and $\pi_i^* \geq 0\ \forall i$. The equilibrium market share of firm i is given by

$$s_i^* = s_i^*(\mathbf{a}, \mathbf{c}, \mathbf{u}), \quad 4)$$

and equilibrium profit of firm i, π_i^*, is obtained by inserting $\mathbf{p}^*$ and $\mathbf{s}^*$ in 1). In the following discussion we will assume that an interior equilibrium exists.

The duopoly model in Armstrong (2002) is a special case of the current model. As shown there, equilibrium market shares are independent of the termination rates. This result does, however, not carry over to the situation where the number of firms is larger than two. The following invariance property holds in the general case:

Proposition 1. If an interior equilibrium exists, equilibrium prices, market shares and profits are identical under $\mathbf{a} = \{a_1, a_2,..., a_N\}$ and $\tilde{\mathbf{a}} = \{a_1 + d, a_2 + d,...., a_N + d\}$ for any d.

Proof. In the first order conditions, 3), termination rates enter as differences, $a_i - a_j$. Hence, equilibrium prices, market shares and profits of all firms $i = 1, 2,..., N$, are unaffected by an identical change in all termination rates. *Q.E.D.*

This result may be compared with the profit neutrality result obtained when the networks compete in two-part tariffs with no network based discrimination [Laffont, Rey and Tirole (1998a), Dessein (2003) and Hahn (2004)]. In general, these authors, and others, are very careful not to overestimate the robustness of the profit neutrality result. In particular the dependence on symmetry is stressed.[11] In contrast, the present

[11]"This analysis of two-part tariffs and nonlinear pricing seems to suggest that the choice of termination charge cannot affect profits at all…. However, it is important to stress that this convenient result is non-robust in a number of dimensions. For instance the assumed cost and demand symmetry across networks plays an important role in the argument", Armstrong (2002), p. 370. "I do not make any claim of robustness of the above profit-neutrality result. In particular, as is clear from the proof of Proposition 3, what is needed is (i) symmetry in demand, .." Dessein (2003) , p. 602. "Note that the profit-neutrality result has been reached under several simplifying assumptions. In particular, we needed the following: Uniformity (symmetry) in demand.", Hahn (2004) , p. 622. Furthermore, footnote 21 in the previous citation stresses that "Symmetry in marginal cost seems also crucial".

result is very robust to asymmetric conditions: The result holds even if firms are subject to different termination rates, different marginal costs and vertical differentiation.

Equilibrium profits

In line with most of the theoretical literature on competition between interconnected networks we take as our point of departure a Hotelling style product differentiation. We assume that all consumers buy one and only one variety and that the market share functions satisfy:

$$\frac{\partial s_j}{\partial p_i} = \sigma \text{, all } j \neq i,\ \sigma > 0 \tag{A.1}$$

$$\frac{\partial s_i}{\partial p_i} = -(N-1)\sigma\ . \tag{A.2}$$

A.1 and A.2 imply multi firm competition in the sense that every firm is in direct competition with all other firms. Anderson, de Palma and Thisse (1992) characterize this property as “strong gross substitutes”. A necessary condition for this property to hold is that $M \geq N - 1$, where M is dimensions of an attribute space and N is the number of competing firms, see Theorem 4.3 p 115 (ibid).

A1 and A2 are satisfied in the model by von Ungern-Sternberg (1991). The spatial interpretation of the von Ungern-Sternberg model is that each firm is located at the corners of an equilateral multidimensional pyramid. Consumers are uniformly distributed on the line segments connecting all corners of the pyramid. The consumers incur a travelling cost when consuming services. In contrast to von Ungern-Sternberg we do not allow corners without a firm.[12] This “no vacant corner assumption” however, allows us to analyse asymmetric equilibria. The assumptions A.1 and A.2 imply that every service is a neighbour to all the other services in the attribute space i.e. that all cross price effects are strictly larger than zero. The parameter σ measures the disutility associated with distance in the attribute space.

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[12] We are not analysing entry and exit in our model. Thus, disallowing vacant corners does not restrict the analysis.

The parameter σ will typically differ between markets (countries) due to differences in the number of competing firms. A.1 and A.2 are fulfilled in the Hotelling duopoly case, as well as in a Salop type circular city (Salop, 1979) with three firms. An example of market shares satisfying (A.1) and (A.2) is the 'Hotelling style' market share function:

$$s_i = \frac{1}{N} + \sigma\Big((N-1)u_i - \sum\nolimits_{j\neq i} u_j - ((N-1)p_i - \sum\nolimits_{j\neq i} p_j)\Big), \qquad 5)$$

where the u's are the firm specific characteristics introduced earlier.

Proposition 2. If an interior equilibrium exists and the market shares obey (A.1) and (A.2) equilibrium profit is given by

$$\pi_i^* = X\, {s_i^*}^2 \left(\frac{1}{(N-1)\sigma} + a_i - \frac{\sum_{j\neq i} a_j}{N-1} \right) \qquad 6)$$

Proof. By inserting the rule for optimal pricing 3) using (A.1) and (A.2) into the profit definition 1) we obtain:

$$\pi_i = s_i X\left(\left(2c_i - \sum\nolimits_{j\neq i} s_j\left(a_i - a_j\right) + \frac{s_i}{\sigma(N-1)}\left(1 + \sum\nolimits_{j\neq i} \sigma\left(a_i - a_j\right)\right)\right) - 2c_i + s_i \sum\nolimits_{j\neq i} s_j\left(a_i - a_j\right)\right)$$

Rearranging this expression using $s_i = s_i^*$, gives 6). *Q.E.D.*

Hence, in accordance with the classical Hotelling duopoly model, equilibrium profit is a function of squared market share. It is easily verified that in symmetric duopoly 6) is given by $\pi_i^* = (s_i^*)^2 / \sigma = 1/4\sigma$.

When market shares are given by 5), some tedious calculations show that the second order condition is $-2\left(1/(N-1)\sigma + a_i - \bar{a}_{-i}\right) < 0$, where $\bar{a}_{-i} = (N-1)^{-1}\sum_{j\neq i} a_j$. Hence, the second order conditions restrict the degree of asymmetry in the mobile termination rates in the market. Furthermore, if termination rates satisfy the second order condition for all operators, the profit function is globally concave in own-price and any interior equilibrium, if it exists, is unique.

A key feature of 6) is that it is separable in equilibrium market shares. As will be shown in the next section, this is a very convenient feature for the current econometric purpose. The separability is a consequence of the, admittedly, very restrictive assumptions A1) and A2).[13]

3. Data and econometric specification

The primary goal of the paper is to test the profit neutrality hypothesis, *Proposition 1* in the previous section. To guide the specification of the econometric model, we use the profit function in 6).

Definitions and descriptive statistics

The data are from Ovum and Wireless Intelligence, and comprise 26 mobile operators in 9 countries located in north-western Europe[14]. The countries are similar in the sense that they are all high-income countries with a very high mobile penetration. Thus they come close to satisfying the assumptions of full participation underlying the theoretical model. The data contain quarterly information on key operator indicators, market statistics and termination rates in the period Q1 2003 to Q3 2006, see Table 1 below for further details.

Let subscript *t* denote period, *i* firm, and *k* the national market of firm *i*. We ignore international and fixed line traffic. In relation to the current model this implies that the mean of the termination rates on outbound traffic of firm *i* is taken over all other mobile operators in firm *i*'s national market, i.e. $\overline{a}_{-it} = 1/(N_k - 1)\sum_{j \neq i} a_{jt}$. We shall discuss some possible implications of this simplification in the next section. To avoid cumbersome notation it is implicitly assumed that the summation is taken only on

[13] Alternatively, if the market shares are of the logit type such that: $\partial s_j / \partial p_i = s_i s_j / \mu$ and $\partial s_i / \partial p_i = -s_i(1 - s_i)/\mu$, it is easily shown that equilibrium profits are given by $\pi_i^* = X(s_i^*)^2 / (1 - s_i^*)\left(\mu / s_i^* + (1 - s_i^*)a_i - \sum_{j \neq i} s_j^* a_j\right)$ .While it is possible to estimate this function, it is not separable in market shares. We will not pursue this specification here.

[14] The countries are Belgium, Denmark, Finland, France, Germany, The Netherlands, Norway, Sweden and The United Kingdom.

operators within each national market $k \in [1,2,..K]$. The number of firms in each national market is not time indexed because there is no operator entry or exit in the markets in the sample period.

Let mtr_{it} denote the termination rate per minute of firm *i* in period *t*. The theoretical model in the previous section assumed unit demand, i.e. that each customer made exactly one call per period. If we assume that this call has a duration of one minute we have that $a_{it} = mtr_{it}$ for each firm *i*. It is now easily verified that if we instead assume that each customer make, say 30 calls of one minute per period, the profit function would be like in 6) with $a_{it} = mtr_{it} 30$. Following this reasoning we let $a_{it} = mtr_{it} M_{kt}, \forall i \in k \in K$, where M_{kt} is the average number of originated mobile minutes per customer in country *k* in period *t*. Consequently, we assume that the customers in market *k* have an inelastic demand equal to M_{kt} each period, and that evolution in M_{kt} is due to exogenous shocks.

As a measure of operator profit we use *ebitda* (*e*arnings *b*efore *i*nterests, *t*axes, *d*epreciations and *a*mortisations). Since there is no investment in the theoretical model, this is the economic performance indicator that comes closest to the profit measure, π_{it}, in equation 6).

Table 1. Descriptive statistics

Variables	*Explanation*	*Mean*	*Std.dev*	*Min*	*Max*
Definitions					
$ebitda_{it}$	Quarterly *e*arnings *b*efore *i*nterest, *t*axes, *d*epreciation and *a*mortisation of firm *i* (in million Euros).	280.81	266.82	-11.05	1007.83
mtr_{it}	Mobile termination rate per minute of firm *i* in Euros.	0.12	0.04	0.06	0.21
s_{it}	Firm *i*'s market share (of customers)	0.30	0.14	0.08	0.58
M_{kt}	Average, quarterly number of mobile minutes in national market *k*	141.08	41.57	74.00	253.00
X_{kt}	Number of mobile customers, in millions, in market *k*	33.87	28.28	3.47	83.12
N_k	Number of mobile network operators in market *k*. Time invariant in sample.	3.58	0.82	2	5
Dependent					
y_{it}	$ebitda_{it} / X_{kt} s_{it}^2$.	121.88	66.68	-249.00	523.02
Explanatory					
a_{it}	$mtr_{it} M_{kt}$.	50.64	20.77	23.83	136.18
$\overline{a}_{-it}$	$1/(N_k - 1)\sum_{j \neq i} mtr_{jt} M_{kt}$.	50.19	17.74	25.38	114.62

Sources: The mobile termination rates are from Ovum. All other variables are from Wireless Intelligence. The data are from Q1 2003-Q3 2006. The number of observations is 258. This comprises 26 operators in Belgium, Denmark, Finland, France, Germany, The Netherlands, Norway, Sweden and the United Kingdom.

Table 1 reveals that the sample comprises firms and markets of considerable heterogeneity. The smallest market in the sample comprises about 3.5 million customers (Norway in 2003) while the largest, Germany, is well above 80 million in 2006. The smallest firm in the sample (relative to market size) has 8 % of the market, while the largest (again relative to market size) has 58%.

Figure 1 shows the evolution in the termination rates per minute, in Eurocents, of the firms having the highest and the lowest *mtr* in each respective market. As may be seen, Denmark is the only country that has maintained symmetric termination rates throughout the whole period, while Finland and Sweden have periods with symmetric termination rates. In general, there have been frequent changes in both levels and the degree of asymmetry. Hence, the data should be informative with respect to the impact of termination rates on profits.

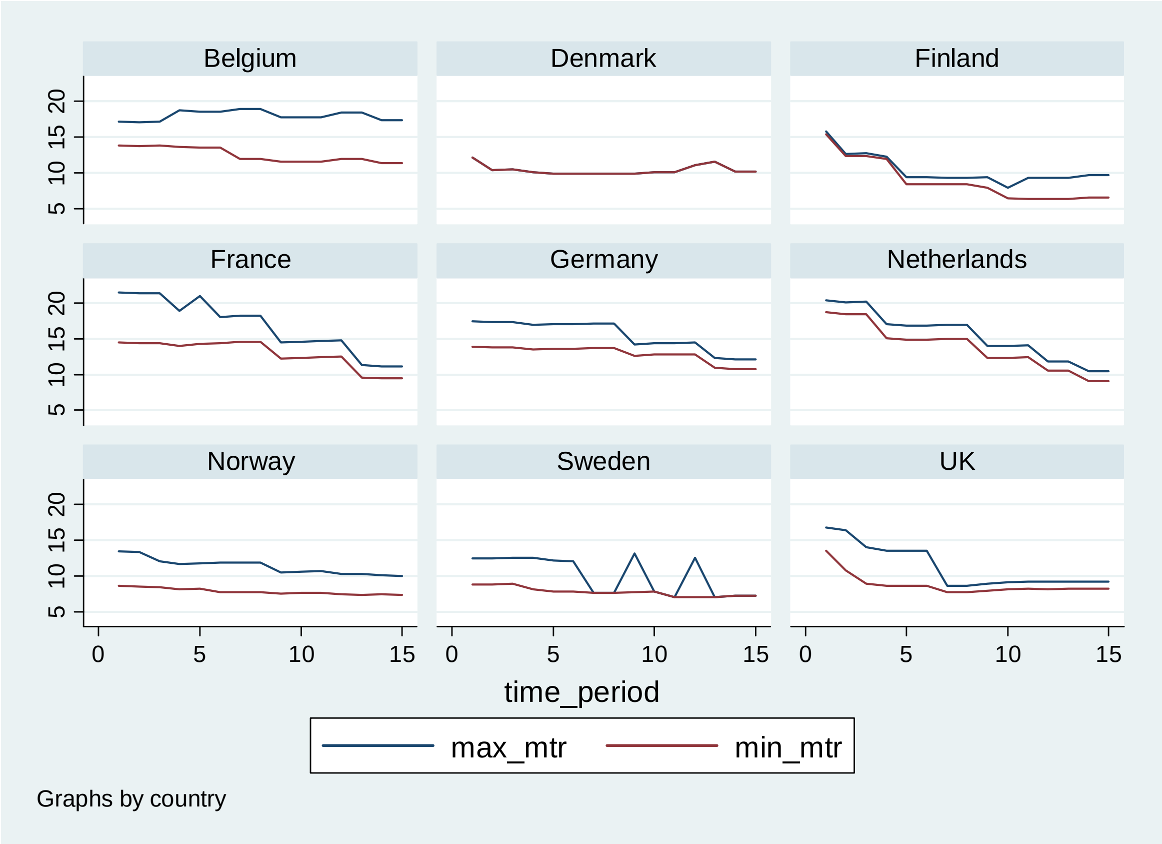

Figure 1. Termination rates per minute in the period 2003 – 2006

The econometric model

Having clarified the empirical representation of the variables, we can now present the econometric model. If we divide both sides of the profit function in 6) by $X_{it}s_{it}^{2}$, we obtain

$$\frac{\pi_{it}}{X_{it}s_{it}^{2}} = \frac{1}{\sigma_k(N_k-1)} + a_{it} - \overline{a}_{-it,} .$$

Hence an econometric specification that nests the theoretical, equilibrium profit function, suitable to the present data, is given by

$$y_{it} = \gamma_i + \beta_1 a_{it} + \beta_2 \bar{a}_{-it} + v_{it}, \quad \forall i,t$$
$$E(v_{it}, v_{it}) = \delta_{it}^2, \quad E(v_{it}, v_{jt}) = \rho_k, \quad (i,j) \in k, \quad E(v_{it}, v_{jt}) = 0 \; (i \in k \vee j \in l \neq k) \quad 7)$$

where $y_{it} = \pi_{it} / X_{it} s_{it}^{\;2}$, γ_i is a firm specific constant and v_{it} is an error term. As is evident from 7) we allow the errors to be heteroskedastic and correlated within clusters defined by each national market. The former accounts for the large heterogeneity in the sample, and the latter for the fact that the firms may be subject to country-specific, unobservable shocks.[15]

The errors, v_{it}, are likely to be correlated with the regressors. Even if all operators are subject to some form of ex ante regulation in the market for termination of voice calls, certain operators may have some discretion in setting their own termination rate. For instance, some operators may be subject merely to a "fair and reasonable price" obligation, see European Regulators Group (2007). In particular, regulators often allow late entrants to set a relatively higher termination rate than incumbents. The motivation is normally that a unilateral high termination rate stimulates post-entry profits and thereby entry.[16] Thus profits and termination rates may to some extent be determined simultaneously.

Table 2. Correlations

	s	*Ebitda*	*ebitda/customer*
Mtr	-0.5**	-0.13*	-0.35**

** $p < 0.01$, * $p < 0.05$

Table 2 shows the correlation between firms' own termination rate and some firm performance indicators. As is seen, there is a clear tendency that small and/or low-profit operators have a higher termination rate. This supports the notion that the model 7) may be subject to simultaneity.

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[15] Correlated error within cross sections in the same country may also be generated by shocks to exchange rates since we measure all monetary variables in Euros and some countries in the sample have their own currency.

[16] See e.g. European Regulators Group (2006). Carter and Wright (2003) and Peitz [2005a, 2005b] shows that a unilateral increase in the termination rate stimulates profits (locally around cost based regulation).

The profit measure, *ebitda*, will in general contain revenue components that are not incorporated in the theoretical model, for instance roaming and various kinds of data traffic, as well as cost components that are not marginal costs. Thus, we allow for a firm specific constant in 7) although the model outlined in the previous section only requires a nation specific constant.

In general, the structure of the theoretical equilibrium profit function makes the econometric specification very robust to unobservable firm specific effects. The unobservable firm specific effects from the theoretical model, i.e. marginal costs and the differentiation parameters, affect profits through market shares only. Since the profit function is separable in equilibrium market shares the specification is robust even to time variation in these unobservable variables.

4. Results

From the discussion in the previous section it is clear that we need a robust panel estimator that can take account of correlations between cross-sections within clusters (countries) as well as endogeneity. Table 3 below presents the results from GMM instrumental variable estimation of the econometric model 7)[17]. The fixed effects are removed by the within transformation.[18] The table displays two sets of estimates: Models (1)-(3) and models (1a)-(3a). Model 1 is identical to model 1a and so forth except that the latter does not include time dummies. We display both sets of results because, in order to implement the cluster option, the time dummies had to be “partialled out” from the other variables, including excluded instruments, in order to get the covariance matrix of orthogonality conditions of full rank, see Baum, Schaffer and Stillman (2006). This implies that the coefficients of the time dummies cannot be displayed and we cannot perform conventional tests on their impact. We therefore present the effect of including them by displaying both sets of results. Appendix A shows the results of estimating the model without the cluster option.

[17] The results presented in this section are based on a sample where the operators in Denmark have been removed. This is because the Danish operators have been subject to symmetric regulation in every quarter, which causes the regressors to be perfectly correlated for these cross-sections.
[18] The estimation is performed in the module xtivreg2 for Stata using the gmm, robust, cluster option. Prior to estimating the models in Table 3 we ran some regressions with explicit firm dummies and tested for heteroskedasticity. All tests revealed a strong presence of heteroskedasticity.

To identify the parameters in the model we need a set of instrumental variables - that is variables that are a) uncorrelated with the error term and b) correlated with the explanatory variables. The candidate instruments are $\mathbf{z} = a_{it-1}, \bar{a}_{-it-1}, s_{it-1}, (ebitda/cust)_{it-1}$. Let us start with b) correlation with the explanatory variables: The first two variables in z will be correlated with the explanatory variables whenever there is some inertia in the termination rates. Current termination rates may be correlated with the last two variables if the regulators use these firm indicators to determine future termination rates, recall Table 2 and the discussion in the previous section. As shown by the first stage regression in Appendix A, there is probably no need to worry about weak instruments. The Shea R^2 from the first stage regressions is in the range of 0.44-0.48.

Why should $\mathbf{z}$ be valid? Regarding a_{it-1} and $\bar{a}_{-it}$ the intuitive argument is that the first lag of the right hand side variables is valid instrumental candidates in the static regression because it is the *current* termination rates that affect profits – lagged termination rates do not affect contemporary profits except possibly indirectly via inertia in the pricing decision. The same argument holds for s_{it-1} and $(ebitda/cust)_{it-1}$ - past performance should not affect profit in a static model.

The latter two proposed instruments highlight the fact that the arguments for the orthogonality of $\mathbf{z}$ depend critically on the assumption that the estimated model is in fact static. If the true model is dynamic, $\mathbf{z}$ will be correlated with the omitted lagged endogenous variable and hence invalid. There is however nothing to indicate that this is the case. In models (2) and (2a) $\mathbf{z}$ is used as excluded instruments. As is evident from Table 3, the Hansen J test does not reject null of valid instruments. The same holds for regressions using further lags of the variables in $\mathbf{z}$.[19]

It is tempting to infer that if the model is in fact static, then y_{it-1} itself should be a valid instrument. The models (3) and (3a) use $\mathbf{z}$ and y_{it-1} as excluded instruments and test whether y_{it-1} is suspect. Neither the Hansen J nor the C statistics is able to reject the null

[19] Results not shown here.

of validity[20]. Appendix C shows the results from estimating a dynamic first differenced model with the Arellano Bond estimator, Arellano Bond (1991). As can be seen, we cannot reject that the coefficient of the lagged endogenous variable is zero at any conventional level of significance.

Table 3. Termination rates and profit: GMM cluster fixed effects[1]

Model: $y_{it} = \gamma_i + \beta_1 a_{it} + \beta_2 \bar{a}_{-it} + v_{it}$

	(1)[2]	*(2)*[3]	*(3)*[4]	*(1a)*[2]	*(2a)*[3]	*(3a)*[4]
a_{it}	1.17**	1.18**	1.16**	1.16**	1.27***	1.26***
	(0.56)	(0.53)	(0.52)	(0.50)	(0.44)	(0.44)
$\bar{a}_{-it}$	-0.57	-0.70**	-0.68**	-0.62*	-0.78***	-0.74***
	(0.35)	(0.32)	(0.32)	(0.37)	(0.29)	(0.28)
Time dummies	Yes	Yes	Yes	No	No	No
R^2	0.05	0.05	0.05	0.05	0.05	0.05
Obs	236	231	231	236	231	231
Firms	22	21	21	22	21	21
Diagnostics[6]						
Hansen J		0.56	0.70		0.62	0.76
C Statistic			0.60			0.64
Endogeneity	0.11	0.09	0.06	0.26	0.18	0.19

Notes:
1) The variables are defined in table 1. Standard errors in parentheses. ***, ** and * indicate significance at the 0.01%, 0.05% and 0.1% level respectively. All models use the within transformation (fixed effects) to handle the firm specific constants. The estimation method is two-step GMM with standard errors robust to arbitrary heteroskedasticity and arbitrary correlation within countries using the xtivreg2 package for Stata. In the estimation of (1)-(3) the time dummies are "partialled out", to get the covariance matrix of orthogonality conditions of full rank.
2) The excluded instruments are the first lag of a and $\bar{a}$
3) The excluded instruments are the first lag of a , $\bar{a}$, s and *ebitda/customer*
4) The excluded instruments are the first lag of a , $\bar{a}$, s , *ebitda/customer* and y
5) All diagnostics report robust p-values. Hansen J is the Sargan-Hansen test of over-identifying restrictions. The C statistics is the "difference-in-Sargan test" of a subset of orthogonality conditions. The instrument tested is the lagged endogenous variable, y . Endogeneity is a test of the null hypothesis that a and $\bar{a}$ are exogenous.

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[20] However, as shown by Nickell (1981) the coefficient of the lagged endogenous variable is biased downwards in a fixed effects regression - y_{it-1} is correlated with the contemporary error term by construction. Thus, the failure to reject y_{it-1} as a suspect instrument in models (3) and (3a) questions the strength of the Hansen J and C-statistics in the present context.

The last row in Table 3 reports the test statistics for the null hypothesis that a_{it} and $\overline{a}_{-it}$ are in fact exogenous variables. We see that exogeneity is rejected at the 10% level for models (2) and (3), but not for the other models. Given strong apriori suppositions of endogeneity, and a reluctance to rely on the models with no time dummies, we proceed with the current estimates. Model (2) is the preferred.

Turning to the estimated coefficients we see that, except for the exactly identified models (1) and (1a), the coefficients are significant at the 5% level for the models with time dummies, and at the 1% level for the models without time dummies. The estimates are slightly higher in absolute value in the model without time dummies.

In all models the coefficients have the expected sign - an increase in the own termination rate increases y_{it}, and an increase in competitors' average termination rate decreases y_{it} (see the next section for interpretation). Moreover, the coefficients are close to 1 and -1 as predicted by the theoretical model.

Consider the profit neutrality hypothesis, i.e. that an identical change in all termination rates in the market does not affect profits. Let $a(h) = \{a_{1t} + h, a_{2t} + h, +.. + a_{Nr} + h\}$. Using 6) and 7) we find that profit neutrality requires that

$$\frac{\partial \pi_{it}}{\partial h} = s_{it}{}^2 X \left(\beta_1 + \beta_2 + 2\frac{\partial s_{it}}{\partial h}\frac{\pi_{it}}{s_{it}} \right) = 0, \quad \forall i \,. \qquad 8)$$

A key property of the theoretical model is that market shares are unaffected by an identical change in all termination rates in the market i.e., $\partial s_{it} / \partial h = 0$. We leave this as an untested assumption in this paper[21]. Conditioned on this, profit neutrality requires that $\beta_1 + \beta_2 = 0$. Table 4 below shows the results of testing profit neutrality based on the previous empirical results.

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[21] We have not attempted to estimate market shares as a function of termination rates in this paper. The reason is lack of instruments: Market shares are subject to a high degree of inertia. Hence, contrary to estimation of profit functions, we cannot use lagged values of termination rates as instruments.

Table 4. Tests of profit neutrality

	1	*2*	*3*	*1a*	*2a*	*3a*
Ho: $\beta_1 = \beta_2$	0.09	0.13	0.14	0.07	0.09	0.07

P-value reported. Test statistics are obtained from the corresponding models in Table 3.

As seen from Table 4, neither model rejects the null at the 5% level. The preferred model, 2), does not reject the null at the 10% level (prob value=0.13). We conclude that we cannot reject that the operator's profits are unaffected by an identical change in all termination rates[22].

Discussion

The results give no strong support for the concern raised in the literature that the *level* of termination rates may be used as collusive device by operators - recall the results form symmetric equilibrium that operators prefer a high level when competing in linear prices [Armstrong (1998), Laffont Rey and Tirole (1998a)], and a low level when competing in two-part tariffs with network based discrimination [Gans and King (2001)].

Although the current model does not explicitly consider price structure, i.e. the pricing of the components in the bundle of subscription and calls, the profit neutrality result is consistent with a key special case in the theoretical literature, namely that of competition with two-part tariffs with no network based discrimination in symmetric duopoly, Laffont Rey and Tirole (1998a). In this model the fall in the call price following a decrease in the termination rates is exactly matched by an increase in the subscription fee leaving profit unchanged. This is a 100% percent "waterbed effect". A waterbed effect exists when downward adjustment in one price (e.g. termination) leads to an upward adjustment in another price. Genakos and Valletti (2008) also find a significant waterbed effect.

The profit neutrality result in the present paper is consistent with a 100% waterbed effect. The European Commission (2008) expects a reduction in termination rates to

[22] It should be mentioned that this does not mean that we can accept the null hypothesis. Indeed, neither can we reject that there is a small but positive effect on operators' profit.

benefit consumers in terms of lower prices. There are strong theoretical reasons to believe that a reduction of all termination rates will lead to lower call prices. However, the present results are consistent with the conjecture that this reduction will be accompanied by a raise in other prices i.e. subscription charges, thus leaving profits and consumer benefits roughly unchanged.

Further research should look into the effects of changes in operator specific termination rates on profit and market shares[23]. Apart from providing a test on the assumption underlying the present profit neutrality result, confer equation 8), this is an important step in assessing the impact of a reduction in termination rate *asymmetry* as proposed by the European Comission (2008). To interpret the present results note that 7) implies

$$\frac{\partial y_{it}}{\partial a_{it}} = \frac{1}{Xs_{it}^2}\left(\frac{\partial \pi_{it}}{\partial a_{it}} - 2\frac{\pi_{it}}{s_{it}}\frac{\partial s_{it}}{\partial a_{it}}\right) = \beta_1$$

$$\frac{\partial y_{it}}{\partial \overline{a}_{-it}} = \frac{1}{Xs_{it}^2}\left(\frac{\partial \pi_{it}}{\partial \overline{a}_{-it}} - 2\frac{\pi_{it}}{s_{it}}\frac{\partial s_{it}}{\partial \overline{a}_{-it}}\right) = \beta_2 ,$$

Thus, inference on the effect of a change in the termination rate structure on profits based on the present results requires information on the marginal effect on market shares. Awaiting empirical evidence we may note the following theoretical results: In the two-firm model $\partial s_i / \partial a_i = \partial s_i / \partial a_j = 0$ as shown by Armstrong (2002). Andersson (2009), finds that $\partial s_i / \partial a_i > 0$ and $\partial s_i / \partial \overline{a} < 0$, analysing the current model in a market with three firms. Drawing on these results, we assert that the empirical results are consistent with the intuition that an increase in own (competitors') termination rate increase (decrease) profit.

[23] It would also be useful to derive and estimate profit functions relaxing some of the assumptions in the current model. For instance theoretical models that take a fixed network into account, see e.g Armstrong and Wright (2008) and Hansen (2006), suggest that if the total number of mobile subscribers is elastic, the mobile operators gain from a symmetric increase in MTRs. This may be consistent with the current results

5. Concluding remarks

We set up a theoretical model of multi-firm competition between interconnected, asymmetric mobile networks. The key assumptions are that the demand for calls is inelastic and identical between operators, and that markets are fully penetrated. We show that the operators' equilibrium profit is unaffected by an identical change in all termination rates in the market. Taking this model to a data set comprising mobile operators in mature European markets we find that the econometric model performs well. The main result is that we cannot reject that profits are unaffected by an identical change in all mobile termination rates in the market.

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Appendix A

Table A1. Termination rates and profit. GMM fixed effects, no clusters

$$\text{Model: } y_{it} = \gamma_i + \beta_1 a_{it} + \beta_2 \overline{a}_{-it} + v_{it}$$

	(1)	*(2)*	*(3)*	*(1a)*	*(2a)*	*(3a)*
a_{it}	1.17	1.20	1.18	1.16	1.26	1.23
	(0.46)	(0.45)	(0.44)	(0.50)	(0.49)	(0.49)
$\overline{a}_{-it}$	-0.57	-0.66	-0.61	-0.62	-0.74	-0.69
	(0.45)	(0.44)	(0.43)	(0.48)	(0.48)	(0.47)
Time dummies	Yes	Yes	Yes	No	No	No
R2	0.17	0.16	0.16	0.05	0.05	0.05
N	236	231	231	236	231	231
N_g	22	21	21	22	21	21
Hansen J		0.48	0.65		0.58	0.74
C Statistics		0.59	0.67		0.64	0.71
Endogeneity	0.08	0.06	0.06	0.15	0.10	0.11

Notes, see Table 3.

Appendix B

Table B1. First stage regressions*

	(1)	*(1a)*	*(2)*	*(2a)*	*(3)*	*(3a)*
	a_{it}	$\bar{a}_{-it}$	a_{it}	$\bar{a}_{-it}$	a_{it}	$\bar{a}_{-it}$
a_{it-1}	0.78	0.14	0.83	0.15	0.82	0.15
	(11.24)	(2.70)	(18.09)	(3.12)	(17.56)	(3.47)
$\bar{a}_{-it}$	-0.08	0.55	-0.12	0.55	-0.12	0.55
	(-1.28)	(7.29)	(-3.24)	(7.83)	(-4.78)	(8.59)
s_{it-1}			-6.59	8.65	-4.72	8.35
			(-0.43)	(0.45)	(-0.35)	(0.38)
$(ebitda/cust)_{t-1}$			-0.05	-0.06	-0.07	-0.06
			(-1.45)	(-3.39)	(-0.75)	(-0.97)
y_{it-1}					0.01	0.00
					(0.18)	(-0.05)
Shea R^2	0.45	0.44	0.47	0.45	0.48	0.45
N	236	236	231	231	231	231
N_g	22	22	21	21	21	21

* t values in parentheses.

Appendix C. Dynamic models

Table C1. Termination rates and profits: Arellano-Bond dynamic panel[1]

Model: $y_{it} = \gamma_i + \beta_0 y_{it-1} + \beta_1 a_{it} + \beta_2 \bar{a}_{-it} + v_{it}$

Variable	*(1)*[2]	*(2)*[2]
y_{it-1}	0.02	0.07
	(0.09)	(0.10)
a_{it}	1.10	1.45*
	(0.73)	(0.83)
$\bar{a}_{-it}$	-0.61	-1.15
	(0.90)	(0.89)
Time dummies	yes	no
Obs	228	228
Firms	21	21
Diagnostics[3]		
AR(1)	-1.78*	-1.71*
AR(2)	-0.04	-0.27
Sargan	1.94	18.29

Notes:
1) The variables are defined in Table 1. Robust standard errors in parentheses. * denotes significance at the 10% level. The model uses first differences to handle the firm specific effects. The estimation method is Arellano-Bond dynamic panel data using the xtabond package for Stata, see Arellano and Bond (1991). The reported estimates are first step, except Sargan which is two-step.
2) a_{it} and $\bar{a}_{-it}$ are treated as endogeneous with the second lags of *s* and *ebitda/cust* as additional instruments. All valid orthogonality conditions up to 5 lags are used.
3) AR(1) is the Arellano-Bond test that average autocovariance in residuals of order 1 is 0, AR(2) is the corresponding test of average autocovariance of order 2. Sargan is the Sargan-Hansen test of over-identifying restrictions. The p-values of both Sargan statistics are 1, note however that the Sargan-Hansen statistics in these model are well known to have little power.

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