Welfare Analysis of Regulating Mobile Termination Rates in the UK with an Application to the Orange/T-Mobile Merger*

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Abstract

We present a calibrated model of the UK mobile telephony market with five mobile networks; calls to and from the fixed network; network-based price discrimination; and call externalities. Our results show that reducing mobile termination rates broadly in line with the recent European Commission *Recommendation* to either "pure long-run incremental cost"; reciprocal termination charges with fixed networks; or "bill-and-keep" (i.e. zero termination rates), increases social welfare, consumer surplus and networks' profits. Depending on the strength of call externalities, social welfare may increase by as much as £700 million to £2.7 billion per year, with bill-and-keep leading to the highest increase in welfare. We also apply the model to estimate the welfare effects of the recently-approved merger between Orange and T-Mobile under different scenarios concerning MTRs, and show that consumer surplus is expected to decrease strongly.

Keywords: telecommunications, regulation, mobile termination rates, network effects, welfare, calibration

JEL Codes: D43, L13, L51, L96

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1 Introduction

Mobile termination rates (MTRs) are the charges that mobile firms levy on fixed networks and other mobile operators for completing, or "terminating", calls on their networks. According to a widely-accepted theory, while competition between mobile networks to attract new customers may be fierce, in the absence of regulation they will still charge excessive prices to other networks for terminating calls to their subscribers. Concerns about mobile call termination being a bottleneck service, and a history of high termination rates, have led to the regulation of MTRs in every country in the European Union, and in numerous other countries around the world.[1]

Until recently, the approach to regulating MTRs adopted by most European regulatory authorities, including Ofcom in the UK, has been to allow for total cost recovery based on fully-allocated cost models.[2] This approach has been increasingly called into question, however, by a new body of economic literature which highlights the two-sided nature of mobile interconnection markets and the significant role that call externalities play in the analysis of competition, equilibrium pricing, and entry in these markets.[3] Impetus for change has also come from the entry of new mobile network operators in many European countries, who argue that their growth and profitability have been hampered by high MTRs and the significant levels of on-net/off-net price discrimination adopted by incumbent mobile network operators (MNOs).[4]

In May 2009, the European Commission (EC, 2009a) issued a *Recommendation on the Regulatory Treatment of Fixed and Mobile Termination Rates in the EU* which embodied much of this new economic thinking, and proposed dramatic reductions in MTRs to reflect the actual incremental costs of providing voice call termination services to third parties.[5]. Ofcom subsequently published a consultation document (Ofcom, 2009a) which reconsidered the pros and cons of a number of alternative approaches to regulating MTRs discussed in the EC *Recommendation.* These were: (i) pricing at "pure long-run incremental cost" ("pure LRIC"), broadly the approach recommended by the EC;[6] (ii) imposing reciprocity with fixed networks, i.e. setting

[1] See Armstrong (2002, Section 3.1), Wright (2002) and Armstrong and Wright (2009a) for the standard theory. The characterization of mobile call termination as a monopoly or "bottleneck" service assumes that mobile operators can make take-it-or-leave-it offers to fixed-line operators and to each other, which is typically justified by reference to various interconnectivity obligations. Binmore and Harbord (2005) question this assumption, and provide an analysis of mobile call termination instead as a bilateral-monopoly bargaining problem. See also Armstrong and Wright (2007, Section 3.5).

[2] Until April 2011 Ofcom regulated the termination charges of the five UK mobile operators at "long-run incremental cost plus" ("LRIC +"), using a detailed cost model to estimate "LRIC +" by allocating the fixed and common costs of a hypothetical efficient network operator over mobile retail and wholesale services.

[3] See, for example, DeGraba (2003); Jeon *et al.* (2004); Berger (2004) (2005); Hoernig (2007); Calzada and Valletti (2008); Hermalin and Katz (2009); Armstrong and Wright (2009b); Cabral (2011); and Hoernig (2009). Harbord and Pagnozzi (2010) provide a survey of much of this literature.

[4] See the European "mobile challengers" web page for some industry views on these issues (www.mobilechallengers.eu).

[5] See also the accompanying documents (EC, 2009b; 2009c). The Commission recommended reducing MTRs by eliminating costs which are common between services from regulated termination charges. According to the Commission, this could result in a decrease in average MTRs in Europe from approximately 8.55 euro cents per minute in 2008 to 2.5 euro cents per minute or less by 2012. While the Commission's recommendation also deals with termination rates on fixed networks, mobile termination rates have typically been ten times higher than fixed termination rates in Europe. The latter ranged from 0.57 to 1.13 euro cents per minute and so have been much less of a concern.

[6] Ofcom (2009a) used the term "long-run marginal cost" (LRMC) to refer to the EC's "LRIC" proposal, and "pure LRIC" in its more recent Statement (Ofcom 2011). Since the EC's terminology corresponds more closely to common usage, we have adopted it in this paper.

mobile termination charges to match the regulated rates of fixed-line network operators; and (iii) adopting "bill-and-keep", which would effectively abolish mobile termination charges by setting them equal to zero.

While the first option is in line with the EC's *Recommendation*, reciprocity with fixed networks would also significantly reduce MTRs. Bill-and-keep would entail the most dramatic change in policy, but variants of it have already been adopted in a number of countries (such as the USA, Canada, Hong Kong and Singapore: see Harbord and Pagnozzi, 2010; Analysys Mason, 2008), and it was recently recommended by the European Regulators' Group (ERG, 2009). In March 2011 Ofcom published its decision (in Ofcom 2011) requiring UK mobile operators to reduce MTRs from values currently exceeding 4 pence per minute (ppm) to 0.69ppm (its estimate of "pure LRIC") by 2014/15. The reductions to be imposed thus fall short of adopting bill-and-keep, but nevertheless reduce termination charges by an order of magnitude.[7]

Ofcom (2009a) discussed the pros and cons of these various approaches in a purely qualitative and largely informal way.[8] The EC *Recommendation* was also largely based upon purely qualitative argument, although as noted, these arguments have been the subject of a great deal of formal economic modelling in recent years, and the *Recommendation* is broadly consistent with the conclusions which seem to emerge from this new literature.[9] What has been lacking, therefore, is a rigorous quantitative assessment of the welfare consequences of adopting one or another of the alternatives being discussed. The main purpose in this paper is to provide such an assessment for the UK mobile market.

Building on the standard model employed by nearly all economists to analyze competition, pricing and welfare in network markets such as mobile telephony, we estimate the impact on total welfare, consumer surplus and producer surplus of a decrease in MTRs in the UK mobile market from their current regulated levels to one or another of the alternatives described above. Our quantitative analysis is based on Hoernig (2010), which provides an analytically tractable model of competition between multiple mobile networks with asymmetries in size and costs and allows us to determine both consumer surplus and networks' profits in the imperfectly competitive equilibrium. The main obstacle to applying models of telecommunications competition to real-world markets to date has been the need to assume either a duopoly market, or symmetric firms, since models with several asymmetric networks were considered intractable. Few real-world mobile markets in Europe or elsewhere satisfy either of these assumptions, however.

We calibrate this model to the UK mobile telephony market allowing for five mobile networks, calls to and from the fixed network, network-based price discrimination, and call externalities, and solve for the equilibrium multi-part tariffs under alternative assumptions concerning the

[7]Regulators around Europe are imposing similar reductions, for example in Holland, Austria, Belgium and Portugal. Elsewhere, in New Zealand the telecoms regulator (ComCom) has recently announced its intention to impose steep reductions in MTRs, leaving open the possibility of abolishing them altogether by introducing "bill-and-keep".

[8]Ofcom (2007, Annex 19) reports the results of a formal welfare analysis which was intended to provide '*an order of magnitude indication of the consumer welfare gain from regulating MCT charges*'. As Ofcom itself recognized, however (in paragraph A17:15), this analysis is unable to account for such crucial factors as call externalities, imperfect competition and price discrimination, and as such is not well-suited to the task of estimating the welfare gains from reducing MTRs.

[9]Section 4 and Annex of EC (2009c) provide the Commission staff's own estimate of the welfare effects of following the *Recommendation*. This calculation is performed at an aggregate level for the whole of the European Union for the period 2007 – 2012, and the resulting welfare gain is found to be at most 1 billion Euros, if not slightly negative. As with Ofcom's 2007 model, this computation is incapable of capturing the effects of call externalities, imperfect competition and asymmetries between mobile operators.

level of MTRs and the ratio of receiver to sender benefits (the call externality parameter in our model). Our results in Section 4.1 show that although consumer surplus and economic welfare *may* decrease *in the mobile market considered in isolation* as we reduce the level of MTRs, aggregate welfare *and* consumer surplus increase in the telecommunications market as a whole for all reasonable values of the call externality parameter. Depending on the strength of call externalities, our model predicts market-wide welfare improvements of £700 million to £2.7 billion per annum, with bill-and-keep resulting in the greatest increase in overall welfare.

A number of recent papers have argued that reducing MTRs will necessarily reduce consumer surplus, and possibly welfare, in the mobile market (Gans and King, 2001; Hoernig, 2008; Armstrong and Wright, 2009a).[10] Specifically, high *fixed-to-mobile termination charges* create profits for mobile firms, some or all of which is passed on to mobile subscribers via the "waterbed effect".[11] Hence mobile subscribers should prefer fixed-to-mobile termination rates set at the monopoly (i.e. profit-maximizing) level. In addition to this effect, mobile subscribers may benefit from high *mobile-to-mobile termination rates,* since these make off-net calls more expensive than on-net calls, creating network effects which favour larger networks. This intensifies competition between networks to attract subscribers, which reduces their equilibrium subscription charges. The much-cited result is that equilibrium consumer surplus on mobile networks is increasing in the level of the mobile-to-mobile termination rate (Gans and King, 2001; Armstrong and Wright, 2009a).

As we discuss in more detail in Section 4.2, however, these arguments are incomplete and do not necessarily survive the inclusion of call externalities and a more realistic number of competing networks in the analysis. It then becomes an empirical question whether a reduction in MTRs will result in an increase or a decrease in welfare and consumer surplus on mobile networks *considered in isolation.* We find that consumer surplus and welfare increase in both the mobile and fixed markets when call externalities are significant. Hence, the trade-off between increasing welfare and maintaining consumer surplus in the mobile market disappears once these factors are taken into account.

Our calibrated model thus provides a rigorous and quantifiable approach to assessing the likely consequences of changes in policy towards regulating MTRs, in the UK and elsewhere. Another natural application is to analyze the recent merger between Orange and T-Mobile, which has created a single firm with about 40% of all UK mobile subscribers. Doing so allows us to predict the merger's effects on economic efficiency, consumer welfare and mobile firms' profits.

We show in Section 5 that with MTRs set at their regulated levels for 2010/11, the overall effect of the merger depends on the strength of call externalities. For low receiver benefits the merger may be welfare-improving (if we allow for the cost savings posited by the merged firms), by moving more subscribers on to a single large network, thus avoiding the inefficiencies associated with high off-net call prices, themselves partially a product of MTRs which exceed

[10] The Royal Economic Society's media briefing "European Decision on Mobile Charges May Not Benefit Customers," emphasizes this aspect of the Armstrong and Wright (2009a) analysis, suggesting that, "*reducing termination charges to very low levels — such as those in the EU's guidance — may come at a cost to mobile subscribers since ultimately mobile operators may end up competing less aggressively for their customers*".

[11] The waterbed effect refers to the phenomenon whereby a reduction (or increase) in MTRs leads to a corresponding increase (or reduction) in subscription charges to mobile subscribers. See Armstrong and Wright (2009a, pp. F284-285). Genakos and Valletti (forthcoming) present some empirical evidence on the strength of this effect in twenty countries. Hoernig (2010) shows that while the FTM waterbed effect is full under multi-part tariffs, it is only partial with linear tariffs.

marginal cost. In other words, the merger may help to "ameliorate" the negative effects of above-cost MTRs, allowed until recently by the UK regulatory authorities.

When call externalities are significant, this result is reversed by the strategic incentive of the newly-merged firm to increase its off-net call prices.[12,13] Hence there is a critical level of the call externality parameter for which the merger becomes harmful to allocative efficiency and welfare. When call externalities are large, we predict that overall welfare losses from the merger exceeding £800 million per year, double the cost savings of £390 - £420 million per year predicted by the companies themselves. With much lower MTRs, such as "pure LRIC" or bill-and-keep, the effects of the merger on aggregate welfare are much reduced, however.

Since the merger reduces the number of competitors in the mobile market, it reduces the intensity of competition between mobile networks. This induces mobile firms to raise the level of their fixed charges, increasing profits at the expense of consumer surplus. The resulting losses in consumer surplus under current MTRs are close to or even exceed £900 million per annum for most values of the ratio of receiver/sender benefits. While for low call externalities these losses in consumer surplus are mirrored by a corresponding increase in profits, with high call externalities due to tariff-mediated network effects and the associated inefficiency profits only increase slightly. If MTRs were significantly reduced prior to the merger (to bill-and-keep), the consumer surplus losses rise to about £1.2 billion per annum, almost all of which translates into higher profits. Although the European Commission has recently approved the merger, subject to certain undertakings agreed by the companies (see EC, 2010), it is difficult to see how these conditions will allay the competition-related concerns illustrated by our calibrated model.[14,15]

Section 2 of the paper describes the market model. Section 3 details our calibration to UK market data and Section 4.1 the results derived using the calibrated model. Section 4.2 discusses these results and considers longer-run implications of reducing MTRs. Section 5 reports on the effects of the Orange/T-Mobile merger, and Section 6 concludes.

2 A Model of the UK Mobile Communications Market

Our model of the UK mobile communications market is a generalization of the network competition models of Laffont *et al.* (1998) and Carter and Wright (1999)(2003) to include many asymmetric networks and calls to and from a fixed network. For more details on the theory see Hoernig (2010).[16] We extend the Hoernig (2010) model by explicitly including a fixed network

[12] It is a standard result of the literature that, in the presence of call externalities, a network's off-net prices are increasing in its own market share. See Jeon *et al.* (2004); Hoernig (2007)(2009b); and Harbord and Pagnozzi (2010).

[13] In addition, for very high levels of the call externality parameter, there is no post-merger equilibrium in which the smallest UK operator (H3G UK) remains in the market.

[14] These conditions are a revised network-sharing agreement with H3G UK and an offer to divest 15 MHz of spectrum at the 1800 MHz level.

[15] In July 2011 Vodafone and Orange announced increases in their pay-as-you-go call charges. Both firms put the blame for these increases on Ofcom's decision to lower mobile termination rates. Our analysis lends itself to a different potential explanation: reduced competition after the merger between T-Mobile and Orange. This seems to be confirmed by the fact that prices are being raised to levels already attained by their competitors.

[16] Several papers have analysed network competition with more than two networks. Symmetric networks are assumed by Calzada and Valletti (2008) and Armstrong and Wright (2009b). Dewenter and Haucap (2005) consider more than two asymmetric networks, but can only solve for the resulting per-minute call prices. Closest to Hoernig (2010) is Thompson, Renard and Wright (2007), which uses a similar demand specification and considers an arbitrary number of networks. However, networks in their model do not price discriminate between

and by determining the market equilibrium following the merger of two networks which retain their separate "brands", or identities, as described below in Section 2.3.[17]

2.1 Model Setup

Networks: We assume $n = 5$ mobile networks of different sizes and one fixed network.[18] Networks face a given fixed cost per subscriber and constant marginal costs for originating and terminating calls. All networks are interconnected and terminate incoming calls at prices given by their respective termination rates. We consider imperfect competition in the mobile market, with consumers perceiving mobile networks as providing substitutable, horizontally differentiated services in a generalized Hotelling fashion, as described below. Consumers perceive fixed and mobile networks as providing non-substitutable services, however, so there is no strategic competition between fixed and mobile networks.

Each mobile network's subscriber market share is denoted by $\alpha_i > 0$, $i = 1, ..., n$, with $\sum_{i=1}^{n} \alpha_i = 1$. Mobile network i incurs a yearly fixed cost per customer of f_i, and has on-net costs of $c_{ii} = c_{oi} + c_{ti}$ per call minute, where the indices o and t stand for origination and termination, respectively. The mobile termination rate (MTR) on network i is denoted a_i, so the per-minute cost of an off-net call from network i to network $j \neq i$ is $c_{ij} = c_{oi} + a_j$.

The fixed network's termination rate (FTR) is $a_f = c_{tf}$, i.e. equal to the cost of call termination on the fixed network. Hence the cost of a call from mobile network i to the fixed network is $c_{if} = c_{oi} + a_f$. The average cost of a call from the fixed to the mobile networks is $c_{fm} = c_{of} + \bar{a}$, where $\bar{a} = \sum_{i=1}^{n} \alpha_i a_i$ is the market-share weighted average MTR. We only consider calls between the fixed and mobile networks and neglect other services on the fixed network, including on-net calls.

Tariffs: Mobile networks offer their retail customers a 'bundle' of mobile access, on-net calls, and off-net calls to other mobile networks and to the fixed network. Each mobile network i charges its subscribers an annual subscription fee F_i,[19] and per-minute call prices of p_{ii} for on-net calls and p_{ij} for off-net calls to network $j \neq i$. We assume that mobile networks charge uniform off-net prices to other mobile networks, i.e. $p_{ij} = p_{ik}$ for $j, k \neq i$. The price of calls to the fixed network is denoted p_{if}. We do not consider other services offered by mobile networks, such as international calls, SMS and data services, as their interaction with mobile voice calls is not clear and is likely to evolve over time.[20]

The fixed network charges a per-minute price p_{fm}, which we assume to be the monopoly price over a total marginal cost of $c_{fo} + \bar{a}$. This assumption is conservative for our purposes because it implies that only half of any decrease in MTRs is passed through to the FTM call price.[21]

on-net and off-net calls, and no closed-form solution for the equilibrium is derived.

[17] This is the relevant case as Orange and T-Mobile have maintained their individual brands following their merger, but share their networks and costs. See Ofcom (2010a, p. 320) and the Everything Everywhere Ltd website (everythingeverywhere.com).

[18] There are a number of fixed-line networks in the UK, including BT, Virgin Media and Cable and Wireless. BT's share of subscribers in 2008 exceeded 60% (Ofcom 2009b, Table 2). We assume a single fixed-line network here, which sets FTM prices as described immediately below.

[19] Yearly subscription fees are used without loss of generality in order to simplify notation and because the time frame under consideration is one calendar year.

[20] Ofcom (2007, A19:16) assumes that the corresponding cross-elasticities of demand are small.

[21] Ofcom (2007, A19.26) assumes that the FTM price involves a fixed retention above cost. This would imply

Consumers: We assume a fixed number of M subscribers in the mobile market, and N subscribers on the fixed network. Each consumer makes calls to all potential recipients on the fixed and mobile networks with equal probability, so in the absence of price differentials we would have a balanced calling pattern. The demand for calls differs between subscribers on mobile networks and on the fixed network, however.

Subscribers receive a fixed utility A_i from being connected to network i;[22] utility from making calls, as a function of call length and the number of calls made; and utility from receiving calls independently of their origin (so there is a call externality). Specifically, the utility derived from making or receiving a call of length q is $u(q)$ or $\beta u(q)$, respectively, where $0 \leq \beta \leq 1$ measures the strength of the call externality. Given a per-minute price p, consumers demand calls of length $q(p)$, with the resulting surplus of $v(p) = u(q(p)) - pq(p)$ and $q(p) = -v'(p)$. In the following we will simplify notation by denoting $q_{ij} = q(p_{ij})$, $u_{ij} = u(q_{ij})$, $v_{ij} = v(p_{ij})$ etc. .

A single consumer's surplus from a given tariff is the sum of the net utility from making and receiving calls minus the subscription fee. Consumers make their choice of network based the net surplus resulting from their own personal preferences for specific networks and the tariffs on offer. A client of network i obtains the following surplus, before taking network preferences into account:

$$
\begin{aligned}
w_i &= M \sum_{j=1}^{n} \alpha_j (v_{ij} + \beta u_{ji}) + N(v_{if} + \beta u_{fi}) - F_i \\
&= M \sum_{j=1}^{n} \alpha_j h_{ij} + N h_{if} - F_i,
\end{aligned}
$$

where $h_{ij} = (v_{ij} + \beta u_{ji})$ and $h_{if} = (v_{if} + \beta u_{fi})$. In matrix notation, this can be written as

$$
w = Mh\alpha + Nh_f - F,
$$

where we have introduced the matrix $h = (h_{ij})_{n\times n}$ and the vectors $w = (w_i)_{n\times 1}$, $\alpha = (\alpha_i)_{n\times 1}$, $h_f = (h_{if})_{n\times 1}$ and $F = (F_i)_{n\times 1}$.

Network preferences, market shares and consumer surplus: We assume that consumers consider mobile networks as offering differentiated products in Hotelling (1929) fashion, generalized to n firms as in Hoernig (2010), and allowing for asymmetric customer valuations as in Carter and Wright (1999). Each network is located at a distinct "node" in consumers preference space. Each consumer's relative preferences for networks are then given by his position on one of $n(n-1)/2$ Hotelling lines, linking every pair of networks, over which consumers are uniformly distributed. Each consumer thus chooses between all of the networks (but in equilibrium always chooses one of the two nearest networks). This model of preferences was chosen so that each network competes directly with every other network for consumers (because there is a line of consumers connecting every two networks), contrary to the well-known Salop model where firms only compete with their two neighbors.

a larger pass-through of 1 and larger increases in welfare due to lower MTRs.

[22] Only the pairwise differences $A_i - A_j$ count and can be calibrated, therefore we normalize $\min_i A_i = 0$. This normalization does not affect the comparison between scenarios presented below.

Assuming a line length of $2/[n(n-1)]$ and firms i and j at the endpoints, the consumer at location x_{ij} will be indifferent between networks i and j if

$$w_i + A_i - tx_{ij} = w_j + A_j - t\left(\frac{2}{n(n-1)} - x_{ij}\right),$$

where $t > 0$ indicates the strength of horizontal preferences. Thus his location is given by

$$x_{ij} = \frac{1}{n(n-1)} + \frac{1}{2t}(w_i + A_i - w_j - A_j).$$

Network i's market share is

$$\alpha_i = \sum_{j\neq i} x_{ij} = \alpha_{0i} + \sigma \sum_{j\neq i}(w_i - w_j),$$

where $\sigma = 1/(2t)$, and $\alpha_{0i} = 1/n + \sigma\sum_{j\neq i}(A_i - A_j)$ captures the ex-ante asymmetries due to consumers' valuations of different networks.[23] Letting $B = (b_{ij})_{n\times n}$, with $b_{ii} = n-1$ and $b_{ij} = -1$ for $j \neq i$, we obtain

$$\alpha = \alpha_0 + \sigma Bw = \alpha_0 + \sigma B\left(Mh\alpha + Nh_f - F\right),$$

which can be rewritten as

$$\alpha = G\alpha_0 + \sigma H\left(Nh_f - F\right), \tag{1}$$

where $G = (I - \sigma MBh)^{-1}$ and $H = GB = (H_{ij})_{n\times n}$. In the presence of call externalities, this is still an implicit condition for market shares, since for $\beta > 0$ both G and H depend indirectly on α through off-net prices.

Letting $A = (A_i)_{n\times 1}$, aggregate consumer surplus on mobile networks, including transport cost, is given by

$$\begin{aligned} S &= M\alpha'(w + A) - M\sum_{i=1}^{n}\sum_{j\neq i}\int_0^{x_{ij}} tzdz \\ &= M\alpha'(w + A) - \frac{M}{4\sigma}\sum_{i=1}^{n}\sum_{j\neq i} x_{ij}^2. \end{aligned}$$

Consumer surplus in the fixed telephony market (FTM and MTF calls) is

$$S^f = NM\sum_{i=1}^{n}\alpha_i(v_{fi} + \beta u_{if}) = NM\alpha' g_f,$$

where $g_{fi} = v_{fi} + \beta u_{if}$ and $g_f = (g_{fi})_{n\times 1}$.

[23] Existence and stability of equilibrium requires that networks be sufficiently differentiated, or that σ is not too large. See Hoernig (2010).

Profits and welfare: Network i's profits are given by

$$\pi_i = M\alpha_i \left(M \sum_{j=1}^{n} \alpha_j R_{ij} + NQ_i + F_i - f_i \right),$$

where $R_{ii} = (p_{ii} - c_{ii})q_{ii}$ for on-net calls and $R_{ij} = (p_{ij} - c_{ij})q_{ij} + (a_i - c_{ti})q_{ji}$ for off-net calls to and from other mobile networks. Furthermore, $Q_i = (p_{if} - c_{if})q_{if} + (a_i - c_{ti})q_{fi}$ are the profits from MTF calls and FTM termination. Joint profits of all mobile networks can be written as

$$\Pi = M\alpha'(MR\alpha + NQ + F - f),$$

where $R = (R_{ij})_{n\times n}$, $Q = (Q_i)_{n\times 1}$ and $f = (f_i)_{n\times 1}$.

The profits of the fixed network from FTM calls are

$$\pi^f = NM \sum_{i=1}^{n} \alpha_i (p_{fm} - c_{fo} - a_i) q_{fm} = NM(p_{fm} - c_{fo} - \bar{a})q_{fm}.$$

Total welfare is then

$$W = S + S^f + \Pi + \pi^f.$$

2.2 Pre-Merger Equilibrium

We model the imperfectly competitive market outcomes as Nash equilibria in multi-part tariffs, i.e. the outcomes that result from mobile networks offering tariffs such that no single network would like to change its offer given the other offers. These equilibrium outcomes determine call prices, subscription fees, the resulting consumer surplus and network profits. In the following we will the state equilibrium prices and fixed fees. The corresponding derivations for the pre- and post-merger cases can be found in Annex A.

In equilibrium, firms charge the following call prices:

$$p_{ii} = \frac{c_{ii}}{1+\beta}, \; p_{if} = c_{if}, \quad p_{ij} = \frac{\sum_{l\neq i} \alpha_l c_{il}}{1-(1+\beta)\alpha_i}, \; j \neq i, \tag{2}$$

That is, as usual efficient on-net prices are set below cost in order to internalize the call externality; MTF prices are set at cost; and off-net prices are set on the basis of perceived off-net cost. These off-net prices increase with network size and the strength of the call externality.

Firm i's equilibrium fixed fee is

$$F_i = f_i - NQ_i + M \sum_{j=1}^{n} \alpha_j \left(\hat{R}_{ij} - R_{ij} \right), \tag{3}$$

where

$$\hat{R}_{ii} = \frac{1}{\sigma M H_{ii}} - \sum_{j=1}^{n} \frac{H_{ji}}{H_{ii}} R_{ij}, \; \hat{R}_{ij} = 0 \; \forall \; j \neq i.$$

Finally, with $\hat{R} = (\hat{R}_{ij})_{n\times n}$, the equilibrium fixed fees can be written as

$$F = f - NQ + M(\hat{R} - R)\alpha,$$

which, after substitution into (1), finally gives rise to the equilibrium condition on market shares

$$[I-\sigma MB(h+R-\hat{R})]\alpha=\alpha_0+\sigma B[N(h_f+Q)-f].$$

In the presence of call externalities the left-hand side depends on α also through h and thus this condition must be solved numerically.

Finally, after substitution of the equilibrium fixed fees the sum of equilibrium profits in the mobile market can be written as

$$\Pi=M^2\alpha'\hat{R}\alpha.$$

2.3 Post-Merger Equilibrium

We model the merger of two networks by assuming that their brands (or locations in consumers' preference space) are kept while their pricing is determined by a unique profit-maximizing entity. On the one hand, this approach is realistic as long as the merged firm keeps the two brands, and on the other it maintains consumers' preference space, ensuring that pre- and post-merger outcomes can be meaningfully compared.[24]

After the merger, non-merged firms j maximize their profits π_j, while the firm resulting from the merger of firms i and k maximizes the sum of profits $\pi_i+\pi_k$. In equilibrium, non-merged firms continue to set equilibrium call prices as in (2). The merged firm charges the same on-net and MTF prices as before, but different off-net prices:

$$p_{ik}=\frac{c_{oi}+c_{tk}}{1+\beta},\quad p_{ij}=\frac{\sum_{l\neq i,k}\alpha_l c_{il}}{1-(1+\beta)(\alpha_i+\alpha_k)},\ j\neq i,k.$$

Thus the merged brands charge the efficient price for calls to each other, while they set higher off-net call prices to other networks based on the joint market share (rather than individual market shares).

As concerns fixed fees in the post-merger equilibrium, they continue to be given by the expression in (3) for the non-merged firms. Note, though, that the equilibrium market shares and call prices have changed and thus the latter fixed fees will differ from the pre-merger values. In fact, they will be higher due to unilateral effects. As for the merged firms i,k, we have

$$\begin{aligned}\hat{R}_{ii} &= \frac{\frac{H_{kk}}{\sigma M}-\sum_{j=1}^{n}(H_{kk}H_{ji}-H_{ki}H_{jk})R_{ij}}{H_{ii}H_{kk}-H_{ki}H_{ik}},\\ \hat{R}_{ik} &= -\frac{\frac{H_{ki}}{\sigma M}+\sum_{j=1}^{n}(H_{kk}H_{ji}-H_{ki}H_{jk})R_{kj}}{H_{ii}H_{kk}-H_{ki}H_{ik}},\end{aligned}$$

and $\hat{R}_{ij}=0$ for all $j\neq i,k$. The fact that $\hat{R}_{ik}\neq 0$ for the merged firms translates the internalization of the competitive externality that the choice of fixed fee F_i imposes on network k. This internalization is the primary consequence of the joint setting of prices on both merged firms: Fixed fees will be set higher because there is no point in stealing either brand's clients. All further expressions for market shares and profits are as above in the pre-merger case.

[24] We thank a referee for pointing this out.

3 Model Calibration

The model described in Section 2 has been calibrated with data from Ofcom's *Communications Market 2010* report (Ofcom 2010a, Chapter 5) unless indicated otherwise, where we indicate the relevant Ofcom figure with the number x as CMx.[25] This report contains the data for 2009, the last full calender year before the merger of Orange and T-Mobile. As we describe in detail immediately below, the model has been calibrated to observed network costs, subscriber numbers, market shares, call quantities and total revenues. The calibration then follows several successive steps, deriving: 1) demand parameters; 2) horizontal differentiation parameters; and finally 3) preference asymmetry parameters.

The parameter measuring the strength of call externalities (β in our nomenclature) cannot be derived from the data, hence is varied between five levels, from zero (i.e. no call externalities) to the maximal value of 1 (i.e. the receiving party receives the same utility as the sending party). Arguably, a value of at least 0.5 is realistic, even if we allow for some "internalization" of call externalities between individuals in stable calling relationships with one another.[26] All other parameters have been calibrated for each specific value of the call externality β.

All values are given in 2008/09 prices, as these correspond to the scaling of the available data.

Costs on mobile and fixed networks: We assume a long-run marginal or incremental cost of originating and terminating calls on mobile networks of 0.69 ppm in 2008/09 prices, corresponding to Ofcom's current estimate of "pure LRIC" (Ofcom 2011, p. 106). Marginal costs of origination and termination on the fixed network are taken from Ofcom (2009c, Table A2.10) which reports termination costs of 0.198 ppm and origination costs of 0.212 ppm. We assume an average level for BT's regulated termination charge of 0.21 ppm,[27] and use the 2009 mobile termination rates of 4.6 ppm for Vodafone and O2, 4.7 ppm for Orange and T-Mobile, and 5.8 ppm for H3G for the calibration.[28]

Ofcom (2007, A19:18) assumes fixed costs per mobile subscriber of £95.38 per year. We allow for no exogenous fixed costs in our model since we only wish to include the avoidable per subscriber costs faced by networks, which are largely composed of handset subsidies. The value of the latter is determined by the level of fixed fees in our model, which are themselves a function of the intensity of competition between the networks, and hence the levels of the MTRs. In order to avoid this endogeneity problem we assume that exogenous per-customer fixed costs are zero.[29]

Subscriber market shares: Mobile subscriptions by network operator for 2009 have been taken from CM46. These result in the subscriber market shares specified in Table 3.1 below.

[25] These data are available in Excel format at: http://stakeholders.ofcom.org.uk/binaries/research/cmr/753567/E1-UK-TEL.csv (consulted on July 1st, 2011).

[26] See Harbord and Pagnozzi (2010) for a discussion.

[27] Ofcom (2009a), Paragraph 2.18, states: "*Wholesale FCT charges are currently no more than 0.25 pence per minute. BT's actual FCT charges vary by time of day. The average charges are currently between 0.17ppm and 0.25ppm depending on the point of interconnection and the extent of conveyance (eg single/double tandem)*". Our assumed average charge of 0.21 ppm is simply the midpoint between these two figures.

[28] These MTR values correspond to 2006/07 prices of 4.4, 4.5 and 5.5 ppm, and 4.3 and 4.0 ppm, respectively, adjusted by 5% for inflation.

[29] Any truly exogenous fixed cost per customer does not affect our welfare and profit comparisons since it would cancel out when differences are taken.

The total number of mobile subscribers in 2009 was 80.26 million.

Table 3.1 Subscribers and Market Shares, 2009					
	H3G	Vodafone	O2[30]	Orange	T-Mobile[31]
Subscribers (m)	4.94	18.83	22.41	16.89	17.18
Market Shares (%)	6.15	23.46	27.92	21.04	21.41

The mobile virtual network operators (MVNOs), such as Virgin Mobile and Tesco Mobile, are not included as independent firms in our analysis.[32] Tesco Mobile is a 50/50 joint venture between Telefonica O2 UK and Tesco plc, and hence acts as a retail arm of O2. Virgin Mobile was originally formed as a joint venture between T-Mobile and the Virgin Group, however in January 2004 the Virgin Group bought out T-Mobile and subsequently became part of the Virgin Media Group in 2006.[33]

Utility and demand parameters: For each value of the call externality parameter β, we used the marginal costs and market shares reported above to compute equilibrium prices from (2). We have then calibrated linear demand functions $q(p) = a - bp$ for mobile-to-mobile (MTM) calls by matching these predicted prices with the observed demand of $Q = 73,660$ million MTM call minutes per year (CM43) from 80.26 million mobile network subscribers; assumed demand elasticities; and using the model's predictions of the relative proportions of on-net and off-net calls. For better readability these demand parameters are scaled in terms of call minutes to one million other subscribers.

Setting Q equal to total predicted MTM call minutes, we have

$$Q = M^2 \sum_{i,j=1}^{n} \alpha_i \alpha_j \left(a - bp_{ij}\right) = M^2 \left(a - b\tilde{p}\right),$$

with the average price $\tilde{p} = \sum_{i,j=1}^{n} \alpha_i \alpha_j p_{ij}$. The market price elasticity of demand is

$$\varepsilon = -\frac{M^2 \tilde{p} b}{Q}.$$

Combining both expressions, we find

$$a = \frac{1}{M^2} \left(1 - \varepsilon\right) Q, \; b = -\frac{\varepsilon Q}{M^2 \tilde{p}},$$

where the latter depends on β through the average price $\tilde{p}$.

We assume an elasticity of demand for mobile-originated calls of $\varepsilon = -0.5$. This value is consistent with estimates found in the recent literature and with those presented to the UK Competition Commission in 2003.[34] Results when we assume an elasticity of demand of -0.3 for mobile-originated calls are presented in Annex B.

For $\varepsilon = -0.5$, we have $a = 17.15$ and the following values of the demand slope depending on the strength of the call externality:

[30] Includes about 2m Tesco Mobile subscribers.

[31] Includes about 4.5m Virgin Mobile subscribers.

[32] Overall, MVNOs and other service providers using existing mobile networks accounted for 12.7% of mobile subscriptions in 2008 (Ofcom, 2009d, Fig. 4.24).

[33] See http://about.virginmobile.com/aboutus/about/history.

[34] Dewenter and Haucap (2007) have estimated demand elasticities for mobile-originated calls in Austria. They find firm-specific short-run elasticities between -0.26 and -0.40, and long-run elasticities between -0.46 and -1.1. Various estimates of demand elasticities for mobile-originated and fixed-to-mobile calls were presented to the UK

Table 3.2 Demand slope for MTM calls					
	$\beta = 0$	$\beta = 0.25$	$\beta = 0.5$	$\beta = 0.75$	$\beta = 1$
b	1.27	1.20	1.11	1.02	0.93

The demand parameters for mobile-to-fixed calls were calibrated similarly, from the same elasticity, 32.12 million subscribers on the fixed network (CM29), and a total demand of 28,700 million MTF minutes (CM43). This results in $a_{mf} = 16.7$ and $b_{mf} = 6.18$.[35]

On the fixed network there were 32.12 million subscribers (CM29), who demanded 12,440 million FTM call minutes per year (CM40), with a corresponding revenue of £1,450m (CM35).[36] Under the conservative assumption that the fixed network sets a separate profit-maximizing price for FTM calls, i.e. chooses the monopoly price given the underlying cost of origination on the fixed network and termination on mobile networks, the linear demand function calibrated on FTM call minutes leads to the demand parameters $a_{fm} = 13.19$ and $b_{fm} = 0.72$.

Horizontal differentiation parameter: For a given call externality β and the resulting demand parameters, we have calibrated the differentiation parameter σ of the underlying Hotelling model such that the total revenue from mobile subscriptions and metered calls is equal to £10,460m (CM2). Total revenue is given by

$$Revenue = M \sum_{i=1}^{n} \alpha_i \left(M \sum_{j=1}^{n} \alpha_j p_{ij} q_{ij} + N p_{mfi} q_{mfi} + F_i \right).$$

Since revenues depend nonlinearly on σ this condition is solved numerically.

Table 3.3 Differentiation parameter					
	$\beta = 0$	$\beta = 0.25$	$\beta = 0.5$	$\beta = 0.75$	$\beta = 1$
σ	0.000452	0.000446	0.000439	0.000430	0.000420
σ^{stab}	0.004779	0.003650	0.002886	0.002306	0.001837

The calibrated values have always been found in the stable range, i.e. $\sigma < \sigma^{stab}$, where the latter has been determined as indicated in Hoernig (2010).

Asymmetry parameters: Finally, given σ the network asymmetry parameters have been determined, up to an arbitrary normalization which we choose to be $\min_i A_i = 0$. That is, each A_i represents the additional amount per year that a subscriber would be willing to pay for switching to firm i, as compared to the firm with the lowest valuation, if all tariffs were identical.

Letting E be the $(n \times 1)$-vector of ones, we have $\alpha_0 = E/n + \sigma BA$, or

$$BA = \frac{1}{\sigma}(\alpha_0 - E/n) = \frac{1}{\sigma}(\alpha - E/n) - Bw.$$

Competition Commission's 'calls to mobiles' inquiry in 2003 (see Competition Commission, 2003, Table 8.7). These ranged from -0.48 to -0.8 for mobile-originated calls, and from -0.08 to -0.63 for fixed-to-mobile calls. Jerry Hausman submitted estimates for the own-price elasticity of mobile-originated calls of between –0.5 to –0.6 for the USA. Ofcom (2007) stated that a reasonable range for the own-price elasticities was between –0.2 and –0.4 for both mobile-originated and fixed-to-mobile calls, and used the value -0.3 (Figure A19.2).

[35] The values of the demand parameters for MTF calls actually have no effect at all on our results since the price and quantity of these calls remain the same in all scenarios. We present their calibration here for completeness only.

[36] This figure does not include any subscription revenues.

Here the only unknown at this stage is A, but it cannot be determined directly because B has rank $(n-1)$. Letting $A = \tilde{A} - E\tilde{a}_0$ where $E'\tilde{A} = 0$ and $\tilde{a}_0 = \min \tilde{A}$, we have

$$\begin{aligned} BA &= \left(nI - EE'\right)\left(\tilde{A} - E\tilde{a}_0\right) \\ &= nE\tilde{a}_0 - En\tilde{a}_0 + n\tilde{A} - EE'\tilde{A} = n\tilde{A}. \end{aligned}$$

Thus $\tilde{A} = BA/n$, from which the asymmetry parameters A can be determined as follows:

Table 3.4 Asymmetry parameters (£ per year relative to H3G)					
	$\beta = 0$	$\beta = 0.25$	$\beta = 0.5$	$\beta = 0.75$	$\beta = 1$
Vodafone	178	178	178	178	179
O2	221	221	221	220	219
Orange	154	154	154	155	155
T-Mobile	157	157	158	158	159

With these asymmetry parameters the model replicates the 2009 market shares reported in Table 3.1.

4 The Effects of Reducing MTRs

Section 4.1 reports our model predictions. Section 4.2 discusses these results and considers longer-run implications of reducing MTRs.

4.1 Model Predictions

This section reports the predictions of our calibrated model for call externality parameters β of 0, 0.25, 0.5, 0.75 and 1, respectively. All results are reported in £ million per calendar year in 2009 prices. Increases of the variables under consideration, as compared to the base scenario are given by positive values and decreases by negative values.

In our base scenario, mobile networks' termination rates are set at Ofcom's "LRIC+" levels for 2010/11, the final year of the current price control. These are 4.6 ppm for H3G and 4.3 ppm for the four other mobile operators. This base scenario is compared with three other scenarios with MTRs reduced to: (i) Ofcom's current estimate of "pure LRIC"; (ii) the average price of termination on the fixed network; and (iii) zero, i.e. bill-and-keep.

As noted above, equilibrium market shares are determined endogenously in our model. Since they only change marginally compared to their original 2009 values, we do not report them here.

Aggregate effects: As shown in Table 4.1, total welfare, i.e. the sum of social welfare in the mobile and the fixed markets, increases significantly under all three alternative scenarios for reducing MTRs. The extent of the increase depends upon the size of the call externality parameter, and exceeds £2 billion per year when receiver benefits are large (i.e. $\beta > 0.75$).

Table 4.1 Change in Welfare Over "LRIC+" Pricing					
	$\beta = 0$	$\beta = 0.25$	$\beta = 0.5$	$\beta = 0.75$	$\beta = 1$
Pure LRIC	727	1073	1471	1938	2502
Reciprocal with Fixed	757	1124	1547	2042	2638
Bill-and-Keep	765	1140	1572	2076	2683

When β=0 (no call externalities), the increase in aggregate welfare is caused by aligning MTRs more closely to marginal costs, since above-cost MTRs distort call prices upwards and call quantities downwards. In the absence of a fixed network, LRIC-based pricing would always result in the highest welfare increase, since MTM calls are priced at true network cost. Since FTM calls are priced above cost, however, total welfare is further increased as MTRs are reduced below "pure LRIC" since this reduces the monopoly pricing distortion in FTM calls.

When call externalities matter, welfare-maximizing MTRs are always below marginal, or incremental, cost for two reasons. First, in the absence of strategic effects, below-cost MTRs induce networks to "internalize" call externalities by setting off-net prices below cost. Second, since call externalities create strategic incentives for mobile firms to increase their off-net prices, reducing MTRs below marginal cost mitigates this effect.[37] Hence bill-and-keep increasingly dominates LRIC in welfare terms as we increase β from zero to one.

As discussed in more detail in Section 4.2, lowering MTRs reduces network effects and relaxes price competition in the mobile market. This can result in lower levels of mobile consumer surplus for small values of β. Consumer surplus in the fixed market always increases, however, due to the reduction in the FTM call price. In the absence of call externalities (i.e. $\beta = 0$), the former effect dominates and aggregate consumer surplus decreases. For larger values of β this result is reversed, and when $\beta = 1$ aggregate consumer surplus increases by more than £1.2 billion in every scenario (see Table 4.2).

Table 4.2 Change in Consumer Surplus Over "LRIC+" Pricing					
	$\beta = 0$	$\beta = 0.25$	$\beta = 0.5$	$\beta = 0.75$	$\beta = 1$
Pure LRIC	-84	186	491	841	1255
Reciprocal with Fixed	-155	132	456	827	1263
Bill-and-Keep	-191	102	433	811	1255

Finally, the sum of profits in the fixed and mobile markets increases in all scenarios for any value of β (Table 4.3).

Table 4.3 Change in Profits Over "LRIC+" Pricing					
	$\beta = 0$	$\beta = 0.25$	$\beta = 0.5$	$\beta = 0.75$	$\beta = 1$
Pure LRIC	811	887	980	1097	1247
Reciprocal with Fixed	912	992	1091	1215	1375
Bill-and-Keep	956	1038	1139	1266	1428

Mobile telephony: We now consider the mobile market in isolation, that is, the effect of reducing MTRs on consumer surplus, welfare and profits in the mobile market only. As shown in Table 4.4, welfare decreases in the mobile market when the call externality parameter (β) is zero, but increases in all scenarios for higher $\beta's$.

[37] See Armstrong and Wright (2009b), Berger (2004) (2005), Hoernig (2008), and Harbord and Pagnozzi (2010).

Table 4.4 Change in Mobile Welfare Over "LRIC+" Pricing					
	$\beta = 0$	$\beta = 0.25$	$\beta = 0.5$	$\beta = 0.75$	$\beta = 1$
Pure LRIC	-61	285	683	1150	1714
Reciprocal with Fixed	-149	218	641	1136	1731
Bill-and-Keep	-194	182	613	1118	1724

The decrease in welfare when $\beta = 0$ is caused by the reduction in fixed-to-mobile transfers. With higher levels of call externalities, this effect is outweighed by the reduction in off-net call prices and the resulting increase in off-net call volumes (i.e. the "off-net pricing effect"), induced by the lower MTRs. With very high call externalities welfare in the mobile market increases by more than £1.7 billion per annum.

For low values of β, consumer surplus the mobile market (see Table 4.5) decreases for two reasons. Networks' profits per consumer from FTM transfers are reduced, and lower MTRs reduce tariff-mediated network effects. Both result in higher subscription prices via the "waterbed effect" and the reduced intensity of competition between mobile firms (the "competition effect").

Table 4.5 Change in Mobile Consumer Surplus Over "LRIC+" Pricing					
	$\beta = 0$	$\beta = 0.25$	$\beta = 0.5$	$\beta = 0.75$	$\beta = 1$
Pure LRIC	-347	-76	228	579	992
Reciprocal with Fixed	-457	-170	154	525	961
Bill-and-Keep	-511	-217	113	491	935

For higher values of β these effects are outweighed by the off-net pricing effect noted above, and consumer surplus increases whenever $\beta \geq 0.5$. That is, the additional surplus created by the reduction in off-net call prices is at least partly retained by consumers, compensating for the countervailing negative effects.[38]

Mobile networks' profits, on the other hand, increase for all values of β (see Table 4.6) due to the competition effect. Reduced FTM transfers do not effect profits since the waterbed effect is always "full" in our model.

Table 4.6 Change in Mobile Profits Over "LRIC+" Pricing					
	$\beta = 0$	$\beta = 0.25$	$\beta = 0.5$	$\beta = 0.75$	$\beta = 1$
Pure LRIC	286	361	454	571	722
Reciprocal with Fixed	308	388	487	611	771
Bill-and-Keep	317	399	500	626	789

Fixed telephony: Finally, we consider the effects of reducing MTRs on the fixed market. The model includes profits and consumer surplus from FTM calls, and also consumer surplus from receiving MTF calls. Fixed termination rates are set at cost, so there are no termination profits. The estimated values for changes in welfare, consumer surplus and profits in the fixed market do not depend on the size of the call externality, since the mobile-to-fixed price is independent of the level of MTRs.

Welfare in the fixed market increases significantly, for two reasons: First, transfers to mobile networks are reduced, and second, FTM call quantities are brought closer to their efficient level.

[38] See Section 4.2 for a more detailed discussion of these effects.

Table 4.7 Change Over "LRIC+" Pricing			
	Welfare	Consumer Surplus	Profits
Pure LRIC	788	263	525
Reciprocal with Fixed	906	302	604
Bill-and-Keep	959	320	639

Due to the monopoly pricing assumption, the fixed network retains most of this welfare increase in increased profits (see Section 2).

4.2 Effects of Reducing MTRs: Discussion

Our calibrated welfare model provides a rigorous and quantifiable approach to assessing the likely effects of changes in MTRs, taking account of call externalities, calls to and from the fixed network, and a realistic number of firms. Our results show that although consumer surplus and economic welfare *may* decrease in the mobile market *considered in isolation* when MTRs are reduced, overall welfare, consumer surplus and firms' profits increase in the telecommunications market as a whole, for all reasonable values of the call externality parameter. Depending on the strength of call externalities, our model predicts welfare improvements of £700 million to £2.7 billion per annum, with bill-and-keep resulting in the greatest increase in overall welfare.[39] Inclusion of the fixed-line operator and call externalities in the analysis is thus indispensable to assessing the economic effects of reductions in MTRs.

The results of our analysis qualify, or even contradict, some conclusions reached in the recent literature. We discuss these issues in Section 4.2.1 below. Our model also omits certain longer-run effects in assuming that the size of the market (i.e. the total number of mobile subscribers), customers' preferences over mobile networks, and the structure of retail prices (i.e. "calling-party-pays") remain unchanged as MTRs are reduced. We consider each of these issues in Section 4.2.2.

4.2.1 Short-Run Issues

Waterbed and tariff-mediated network effects: A number of recent papers have argued that reductions in MTRs will necessarily reduce consumer surplus, and possibly welfare, in the mobile market, and for two reasons. First, a fixed-to-mobile termination rate above cost results in a flow of termination profits to mobile networks, some or all of which is passed on to mobile subscribers via the "waterbed" effect. Hence mobile subscribers should prefer fixed-to-mobile termination rates set at the monopoly (i.e. profit-maximizing) level. As Armstrong and Wright (2009a, p. F286) put it, "*high FTM termination charges are a means of transferring surplus from fixed callers to mobile recipients*".

Second, mobile subscribers can also benefit from above-cost mobile-to-mobile termination rates, since these make off-net calls more expensive than on-net calls, creating network effects which favour larger networks. This intensifies competition between networks to attract subscribers, which reduces their equilibrium subscription charges. The much-cited result is that

[39] The corresponding estimates for a mobile demand elasticity of -0.3 are about £600 million and £2 billion, respectively. By contrast, the EC's maximum estimate was 1 billion euros for the entire European Union for the period 2007 – 2012, as noted above.

equilibrium consumer surplus on mobile networks is increasing in the level of the mobile-to-mobile termination rate (Gans and King, 2001; Armstrong and Wright, 2009a).[40]

While these arguments have been much aired in recent regulatory debates, they are subject to a number of important caveats. The argument with respect to fixed-to-mobile termination rates is incomplete in two important respects. First, as observed by Armstrong and Wright (2009a, p. F284), even if all fixed-line subscribers have a mobile phone, high termination rates would still create an allocative inefficiency, and hence the gain to mobile subscribers from low subscription charges is always outweighed by the welfare loss on the fixed network from high fixed-to-mobile termination rates. Since most telephone subscribers use both fixed and mobile networks, the increase in economic efficiency and welfare achieved by aligning MTRs more closely with marginal costs benefits telephony users in general.

Second, the argument loses much of its force when call externalities, or receiver benefits, matter. To see this, note that with call externalities the total surplus created on a mobile network by a fixed-to-mobile call can be written as

$$s_{fm} = (a - c_t)q_f + \beta u(q_f),$$

where a is the fixed-to-mobile termination rate, c_t the marginal cost of termination, and q_f the length of the call. An increase in a above marginal cost increases the profits of the mobile network, some or all of which is passed on to mobile subscribers via the waterbed effect, but simultaneously reduces the utility received by the mobile network's subscribers from fixed-to-mobile calls through reducing q_f. With a high ratio of receiver to sender benefits (i.e. the call externality parameter in our model), the latter effect outweighs the former and hence welfare on mobile networks becomes a decreasing function of the level of MTRs.[41,42]

The argument that above-cost, mobile-to-mobile termination rates benefit mobile consumers is also incomplete. As demonstrated by Hoernig (2010), it is only necessarily true in models with at most two mobile networks. With $n > 2$ networks, although a reduction in the mobile-to-mobile termination rate still mitigates network effects, and hence relaxes competition between mobile networks for market share, the reduction in competition may or may not be sufficient to reduce consumer surplus in equilibrium, and it is less likely to do so the more significant are call externalities and the larger is the number of competing networks.

The upshot is that it is an empirical question whether a reduction in fixed-to-mobile and mobile-to-mobile termination charges will result in an increase or a decrease in welfare and consumer surplus on mobile networks *considered in isolation*, especially in markets with more than two firms. In our results, when call externalities are significant *consumer surplus and welfare increase in both the mobile and fixed markets*. Hence, the trade-off between increasing welfare and maintaining consumer surplus in the mobile market disappears once call externalities and a realistic number of networks are taken into account.

Fixed-to-mobile substitution: Our welfare model treats fixed and mobile networks as if they operated in entirely separate markets, with no competitive interaction either at the level

[40] This result has led a number of authors to suggest that mobile networks should prefer to agree on below-cost mobile-to-mobile termination charges, and that such an agreement would harm mobile subscribers who prefer the more intense competition created by higher MTRs.

[41] See Armstrong and Wright (2009b) and Harbord and Pagnozzi (2010, Section 5.1) for further discussion.

[42] A third caveat is of course that the argument for high fixed-to-mobile termination rates depends upon the strength of the waterbed effect, about which we can say little in practice. Some preliminary results can be found in Genakos and Valletti (forthcoming).

of calls or subscriptions. That is, we have not allowed for any substitution between fixed and mobile calls, and nor have we have considered whether changes in mobile termination rates might affect the overall numbers of subscriptions to fixed versus mobile networks.[43]

Recent data indicates that subscriptions to fixed networks are relatively price inelastic,[44] and according to Ofcom (2009d, Fig. 4.62, p.248), more than 80% of all UK households subscribed to both fixed and mobile services in 2009.[45] Hence the assumption of no competitive interaction at the level of access or subscriptions can probably be justified.

Consumers who subscribe to both mobile and fixed networks, however, can choose between the two types of calls, depending on which is cheaper and on whether or not callers have a fixed phone available when they want to place a call. Armstrong and Wright (2009a, Section 3.3) model this form of FTM substitution by assuming that calls made on the FTM demand curve can originate on either fixed or mobile networks, and that consumers will always choose the lower-cost form of communication, i.e. they assume that FTM and MTM calls are perfect substitutes and that callers are never "on the move".

In our calibrated model, the FTM price is always above the highest equilibrium off-net price, even in the merger scenarios considered in Section 5. Thus our results are consistent with the possibility of call substitution between FTM and MTM calls if we interpret the FTM calls observed in the data as calls made by customers of the fixed network who do not have access to a mobile phone when the place their call. Thus explicitly modeling FTM substitution would not change our results.

4.2.2 Long-Run Effects

Market expansion: Mobile operators in Europe have long argued that high MTRs result in mobile firms subsidizing connection and acquisition costs for new subscribers, via the waterbed effect, and that this leads to market expansion which benefits new and existing mobile subscribers. In the presence of such network externalities, socially-optimal MTRs should therefore exceed marginal costs.[46]

Armstrong and Wright (2009a) have provided some theoretical support for this policy. Noting that mobile subscribers' utility increases with both the fixed-to-mobile and mobile-to-mobile termination charges in their duopoly model, they suggest that '*this observation implies that firms and the regulator can use relatively high termination charges as a means to expand the number of mobile subscribers.*' To demonstrate this formally, they consider a "Hotelling model with hinterlands" in which the total number of mobile subscribers is increasing in the utility they derive from joining one or other of the mobile networks. The possibility of market expansion introduces market-level network effects: when a new subscriber joins a network, the utility of the existing subscribers to any network increases since there are now more subscribers they can

[43] In the next Section we consider how changes in mobile termination rates might affect the numbers of subscribers to mobile networks considered in isolation.

[44] See Briglauer *et al.* (2011) and Vogelsang (2010).

[45] This figure fell to 78% in 2010 (see Ofcom 2010b, Fig. 5.67), so a small amount of FTM substitution at this level may be taking place.

[46] Since the Competition Commission's 2003 inquiry, mobile operators in the UK have received (and paid) a "network externality surcharge" on top of their regulated MTRs for this purpose. See Competition Commission (2003, pp. 225-252). In its 2008/09 inquiry, the Competition Commission revisited the issue and decided that a network externality surcharge was no longer justified (see Competition Commission, 2009, Section 4). Network externality surcharges have also been applied in Belgium, Greece, Italy and Sweden (Cullen International, 2008), although the European Commission (EC, 2009b) now recommends against this policy.

call, either on-net or off-net. Armstrong and Wright (2009a) conclude that socially optimal MTRs should exceed the marginal cost of termination, and that the fixed-to-mobile and mobile-to-mobile rates should be set at different levels, if feasible.[47]

As discussed immediately above, these conclusions do not necessarily survive the inclusion of call externalities in the analysis, nor an increase in the number of competing mobile networks. When call externalities matter, a high fixed-to-mobile termination rate does not necessarily increase the surplus of mobile subscribers, since the fixed-to-mobile termination rate which maximizes surplus on mobile networks can be above or below marginal cost, and even below zero. Whether fixed-to-mobile termination rates can be used to increase mobile take-up is therefore an empirical question, which depends upon the strength of call externalities and other market parameters, such as the elasticity of demand for fixed-to-mobile calls.

In mobile markets with more than two firms, mobile subscribers' consumer surplus is not necessarily increasing in the mobile-to-mobile termination rate, either. Indeed, our results show that if call externalities are significant and if a realistic number of networks is taken into account, then mobile consumer surplus is actually *decreasing* in the termination rate.

Further doubt is cast on the market expansion argument by evidence on mobile subscription or penetration rates in bill-and-keep countries versus "calling party network pays" (CPNP) countries with higher MTRs. Recent studies undertaken for Ofcom (Ofcom 2009a, Annexes 5 and 7) find that once data on mobile take-up rates are corrected for multiple subscriptions, which are more common in CPNP countries, there is little measurable difference in penetration rates between bill-and-keep and CPNP countries (see also Analysys Mason, 2008, pp. 7-10). While mobile usage, or call volumes, tend to be much higher in bill-and-keep countries, mobile subscription levels do not appear to depend on the level of MTRs in mature markets.[48]

It is therefore unclear whether reducing either fixed-to-mobile or mobile-to-mobile termination rates will result in a decrease or increase in the overall number of mobile subscribers, and our results reflect this ambiguity. When call externalities are neglected, lower MTRs reduce consumer surplus in the mobile market which could result in a long-run reduction in the number of mobile subscribers. If call externalities matter, on the other hand, then lower MTRs increase mobile-market consumer surplus, and this should lead to market expansion. By holding the number of mobile subscribers fixed, our model is conservative in the sense that it likely underestimates (in Table 4.5) either the decrease or increase in consumer surplus associated with lower termination rates.

Network preferences and long-run market shares: A move to much lower MTRs, or bill-and-keep, should result not only in a more efficient wholesale and retail price structure in the short run, as represented in our model, but also eliminate barriers to growth in the mobile market and result in a medium to long-run tendency for networks' market shares to equalize. As numerous authors have observed, above-cost MTRs exacerbate the network effects associated with "tariff-mediated network externalities", by increasing mobile networks' strategic incentives to set high on-net/off-net price differentials to the detriment of smaller networks and

[47] Armstrong (2002), Wright (2002) and Valletti and Houpis (2005) also found that the welfare-maximizing fixed-to-mobile termination charge is above cost when there is scope for market expansion. These models did not allow for mobile-to-mobile calls, however.

[48] See also ERG (2009, pp. 22-26), which concludes that there is no strong correlation between penetration (or ownership) rates and MTRs.

new entrants.[49] Our analysis assumes that the utility a consumer receives from being connected to a specific network (A_i) remains unchanged as MTRs are reduced, and this results in only marginal changes in the recomputed equilibrium market shares.

Since greater market symmetry should have a procompetitive effect, our short-run analysis may underestimate the longer-run benefits for consumers of reducing MTRs. Table 4.8 presents the changes in aggregate welfare, consumer surplus and profits that would result if, following the introduction of bill-and-keep, network preferences were to equalize completely. Arguably, complete equalization of market shares provides an upper limit on the welfare changes that might be expected under a more realistic future market structure.

Table 4.8 Changes from "LRIC+" Pricing to BaK and Symmetry

	$\beta = 0$	$\beta = 0.25$	$\beta = 0.5$	$\beta = 0.75$	$\beta = 1$
Welfare	1291	1685	2138	2668	3306
Consumer surplus	1592	1886	2217	2596	3040
Profits	-302	-201	-79	72	266

Comparing Table 4.1 with Table 4.8 shows that the increases in total welfare and consumer surplus are significantly larger, while profits increase much less or may even decrease, when we allow for longer-run market share symmetry. (Since values for the fixed market remain unaltered, these figures reflect changes in the mobile market outcomes alone). Hence if we believe that reducing MTRs should increase longer-run competition, our short-run analysis underestimates the longer-run welfare gains from reductions in MTRs.

Receiving party pays: Finally, reducing the level of MTRs may affect the types of tariffs offered by mobile networks. In most "bill-and-keep" (or near bill-and-keep) countries (e.g. Canada, Singapore, Hong Kong, the United States), mobile firms have adopted receiving party pays (RPP), i.e. customers are charged for receiving calls. Cambini and Valletti (2008) and Lopez (2011) argue networks may adopt RPP when MTRs are reduced below cost.[50] So would the reductions in MTRs considered in this paper lead to reception charges for mobile subscribers, and would this increase or decrease economic efficiency and social welfare?

The literature on this subject is still in its infancy, so no definite answer can be given. Jeon *et al.* (2004, pp. 105-107) analyze duopoly competition with network-based price discrimination and reception charges and show that for $\beta < 1$, in any symmetric equilibrium off-net reception charges are either infinite or equal to $c_t - a$ depending on parameter values. For reasonable parameter values, bill-and-keep can lead to reception charges so high that no off-net calls are made. Hermalin and Katz (2009), on the other hand, consider a model in which the strategic motive for increasing off-net prices is absent, implying that networks always set off-net sender and receiver prices equal to "perceived" marginal cost, $c_0 + a$ and $c_t - a$, respectively. Thus if

[49] See Armstrong and Wright (2009b); Cabral (2011), Calzada and Valletti (2008); Hoernig (2007) (2009a); and Harbord and Pagnozzi (2010). Indeed, when call externalities are absent or small, adopting bill-and-keep can result in "negative network effects", and subscribers will, all else equal, prefer to join a smaller network (see Armstrong Wright, 2009, p. F286).

[50] See also EC (2009b, p. 31). In the EC's view, "*RPP may evolve after a reduction of the regulated termination charge or as a response to a Bill and Keep system*". Ofcom (2009a, p. 38), however, views this as "*highly unlikely, given the likely consumer reaction.*"

bill-and-keep were adopted ($a = 0$), the total cost of an off-net call would be divided between the sender and receiver in proportion to the costs incurred on each network. The two models therefore lead to strikingly different predictions concerning profit-maximizing sender and receiver charges for given termination charges, and Hermalin and Katz (2009, p. 30) remark that, "*the importance of such cross-carrier effects is an empirical question that remains to be answered*".[51]

Whatever the theoretical predictions, as noted by Harbord and Pagnozzi (2010, Section 6), existing empirical evidence suggests that mobile networks in bill-and-keep countries do not set very high reception charges. Ofcom (2009a, Annex 9) presents evidence on sender versus reception charges in the United States, and finds that "*all operators for all levels of output charge the same price for both types of calls.*" Analysys Mason (2008) found that while all bill-and-keep countries have RPP retail charging regimes, there exist free incoming call plans in each of these jurisdictions, whose relative importance appears to increase over time (p.4). Hence, as an empirical matter, it is unclear that the adoption of bill-and-keep would necessarily lead to the imposition of significant reception charges for mobile calls.

5 Analysis of the Orange/T-Mobile Merger

Another application of our model is to analyze the merger between Orange and T-Mobile in the UK mobile market, approved by the European Commission in 2010. The two operators merged in May 2010 to form a new company called Everything Everywhere Ltd, which, based on end of 2009 data, had a combined market share of more than 40% of UK mobile subscribers (a total of 34.1 million, including MVNOs such as Virgin Mobile). Our calibrated welfare model allows us to predict the merger's unilateral effects on economic efficiency, consumer welfare and mobile firms' profits.[52]

We capture the effects of the merger by assuming that Orange and T-Mobile maintain their separate identities, or "brands", but jointly decide on their profit-maximizing call prices and subscription charges, as described in detail in Section 2.[53] This means that the number of firms and the consumer preference space remain unchanged in the Hotelling model following the merger. Thus welfare and market outcomes pre- and post-merger can be consistently compared.

We analyze the merger under different assumptions concerning the level of MTRs. First, mobile networks' MTRs are set equal to Ofcom's estimates of "LRIC+" for the final year of the current price control 2010/11, adjusted for inflation to 2008/09 prices. Second, MTRs are set at "pure LRIC" or zero (i.e. bill-and-keep) prior to the merger. All reported results are stated in £ million per calendar year in 2008/09 prices.[54]

[51] Lopez (2011) obtains results which are broadly consistent with those of Jeon *et al.* (2004). He finds that connectivity breakdown is prone to occur when networks distinguish between on-net and off-net call and reception charges. Cambini and Valletti (2008), on the other hand, find that networks' incentives to use off-net/on-net price discrimination to induce connectivity breakdown are reduced when outgoing and incoming calls are complements (specifically, in a model in which each outgoing off-net call results in a fraction $x < 1$ of incoming calls).

[52] Our merger analysis is based on the calibration presented in the Section 3. We present additional values for an MTM demand elasticity of -0.3 in Annex D.

[53] This is the relevant case, since the companies announced that the T-Mobile and Orange brands will continue to operate in the UK for at least 18 months following the merger (see Ofcom 2010a, p. 320).

[54] Increases of the variables under consideration are given by positive values and decreases by negative values. The point of comparison in all cases is the pre-merger outcome under either level of MTRs (LRIC+ or bill-and-keep). Both consumers on the fixed network and the fixed network itself are not affected by the merger, given that MTRs are held fixed. Thus all effects are located in the mobile market.

5.1 Effects of the Merger under 2010/11 MTRs:

With MTRs set at their regulated levels for 2010/11, the welfare effects of the merger depend on the strength of call externalities, or receiver benefits. In the absence of call externalities ($\beta = 0$), the merger reduces welfare only slightly, as a result of a number of competing effects. First, by moving more subscribers on to the largest network, the merger improves welfare by reducing the allocative inefficiency associated with high off-net call prices. That is, subscribers on the merged network benefit from being able to make more efficiently-priced on-net calls. Second, since the merged firms increase their fixed charges by more than other networks, equilibrium market shares increase slightly for the other firms, and decrease for the merged firm (see Table 5.1). This means that a fraction of consumers face higher calling charges for off-net calls on the smaller networks, as well as incurring different Hotelling "transport" costs. Finally, there is an additional, small welfare loss resulting from the fact that a fraction of consumers move on to their least-preferred network H3G (see the calibrated asymmetry parameters in Table 3.4). The overall effect is a welfare loss of £15 million per annum when $\beta = 0$ (see Table 5.2).

Table 5.1 Pre- and Post-merger Market Shares[55]

	Pre-merger	Post-merger				
	(all β)	$\beta = 0$	$\beta = 0.25$	$\beta = 0.5$	$\beta = 0.75$	$\beta = 1$
H3G	6.15	6.81	6.68	6.4	5.53	—
Vodafone	23.46	24.94	24.86	24.69	24.18	—
O2	27.92	29.39	29.31	29.18	28.76	—
Orange	21.04	19.23	19.38	19.67	20.57	—
T-Mobile	21.41	19.63	19.77	20.06	20.95	—

For $\beta > 0$, however, the merged firms increase their off-net prices and aggregate welfare decreases further, with the welfare losses exceeding the cost savings of £390 - £420 million per year predicted by the companies themselves when $\beta \geq 0.75$. Hence for moderate to high call externalities the merger would appear to be detrimental to economic efficiency, even if we allow for all of the cost savings posited by the companies.[56]

The increases in the merged firms' off-net prices also create network effects, reducing the market shares of the other networks. Interestingly, there is no post-merger Nash equilibrium in which H3G remains in the market for β close to 1.

Table 5.2 Merger Effects with 2010/11 MTRs

Change in	$\beta = 0$	$\beta = 0.25$	$\beta = 0.5$	$\beta = 0.75$	$\beta = 1$
Welfare	-15	-45	-186	-800	—
Consumer Surplus	-918	-867	-840	-919	—
Profits	903	821	654	120	—

Since the merger reduces the intensity of competition between the mobile networks, it induces them to raise the level of their fixed charges, increasing profits at the expense of consumer surplus. The resulting losses in consumer surplus exceed £840 million per annum for all values

[55] Included are about 2m Tesco Mobile subscribers on Orange and 4.5m Virgin Mobile subscribers on T-Mobile.

[56] Our estimate of the merger's expected annual cost savings is based on information provided in Orange and T-Mobile (2009). The calculations are detailed in Annex C.

of β. For low values of β the reductions in consumer surplus are closely mirrored by increases in the mobile networks' profits, but for higher values the increase in profits is less, since increases in the merged networks' off-net prices intensify competition through tariff-mediated network effects.

5.2 Effects of the Merger with Lower MTRs

If we perform our calculations with much lower MTRs, such as those proposed in the European Commission *Recommendation* and recently adopted by Ofcom, the (negative or positive) effects of the merger on aggregate welfare are much reduced. We model this by assuming that Ofcom's "pure LRIC" is adopted prior to the merger, with no effect on network preferences. In this case, the merger reduces welfare by £70 to £171 million per year, depending on the value of β (see Table 5.3). If we allow for the companies' claimed cost savings of £390 - £420 million per year (see Annex C), this means that the merger will be welfare improving for all assumed values of the call externality parameter.

But the merger still results in large decreases in consumer surplus for all values of β, exceeding £1.1 billion per annum for all values of β, and these reductions are closely mirrored by increases in networks' profits. Hence even if a regime of very low MTRs were adopted, the merger creates significant welfare losses for consumers and significant additional profits for mobile firms.

Table 5.3 Merger with pure LRIC

Change in	$\beta = 0$	$\beta = 0.25$	$\beta = 0.5$	$\beta = 0.75$	$\beta = 1$
Welfare	-70	-70	-76	-97	-171
Consumer Surplus	-1145	-1135	-1129	-1125	-1126
Profits	1075	1065	1053	1028	955

If instead pure bill-and-keep were adopted before the merger, we find similar changes in welfare and profits, as shown in Table 5.4a.

Table 5.4a Merger under Bill-and-Keep

Change in	$\beta = 0$	$\beta = 0.25$	$\beta = 0.5$	$\beta = 0.75$	$\beta = 1$
Welfare	-71	-70	-71	-75	-90
Consumer Surplus	-1175	-1173	-1175	-1180	-1186
Profits	1104	1102	1104	1104	1096

The adoption of bill-and-keep should result in a medium to long-run tendency for networks' market shares to equalize, however, due to the relationship between MTRs and tariff-mediated network externalities, as argued in Section 4.2.2 above. To capture this, we assume that consumers preferences over networks are equalized both before and after the merger. The resulting post-merger equilibrium market shares are slightly above 20% for each of the non-merging networks, and below 20% for each of the merged networks, since the merged networks set higher subscription charges.

The merger's effect on aggregate welfare now ranges from just over £23 million per year (when $\beta = 0$), to minus £36 million per year (when $\beta = 1$) (see Table 5.4b). The effect on consumer surplus is also somewhat ameliorated, and is less than minus £1.1 billion per year for all values of β. Under bill-and-keep the existing asymmetry between market players evidently has limited impact on our evaluation of merger effects.

Table 5.4b	**Merger under Bill-and-Keep with Preference Symmetry**				
Change in	$\beta = 0$	$\beta = 0.25$	$\beta = 0.5$	$\beta = 0.75$	$\beta = 1$
Welfare	-23	-23	-24	-27	-36
Consumer Surplus	-1069	-1068	-1071	-1077	-1085
Profits	1046	1045	1047	1050	1049

5.3 Discussion

Our analysis shows that with MTRs set at their regulated levels for 2010/11, the aggregate effects of the Orange/T-Mobile merger depend on the strength of call externalities. By moving more subscribers on to a single large network, the merger improves allocative efficiency and welfare for low values of the call externality parameter if we allow for the "synergies" or cost savings posited by the merged firms. This observation provides a stark illustration of the inefficiencies created by the LRIC+ approach to regulating MTRs. In the absence of call externalities, efficiency and welfare (although not consumer surplus) would be increased even further by a merger of all five of the mobile network operators in the UK market into a single monopoly network, so that all mobile-to-mobile calls became more efficiently-priced on-net calls. When receiver benefits matter, this is result is reversed, so there is a critical level of the call externality parameter for which the merger becomes harmful to allocative efficiency.

With much lower MTRs, such as Ofcom's pure LRIC or bill-and-keep, the merger's aggregate effects on welfare and efficiency are much reduced, since off-net call prices are much closer to their efficient level. Nevertheless, the merger significantly reduces competition and consumer surplus in each of the scenarios we have considered. Under the 2010/11 levels of regulated MTRs, these losses are close to £900 million per annum for all values of β. Under bill-and-keep, the consumer surplus losses exceed £1 billion per annum for any level of MTRs, even once we allow for a longer-run tendency for networks' market shares to equalize.

The European Commission has recently approved the merger, subject to certain undertakings agreed by the companies relating to network-sharing arrangements and divestiture of spectrum (see EC, 2010). It is not obvious how these undertakings address the competition and welfare-related concerns illustrated by our calibrated model, however.

6 Conclusions

The traditional regulation of mobile termination rates based on fully-allocated costs (or "long-run incremental cost plus"), results in regulated MTRs an order of magnitude above reasonable estimates of long-run incremental costs on mobile networks, which in turn are much closer to marginal cost. In the presence of call externalities, efficient pricing on mobile networks even requires MTRs below marginal cost. The European Commission's 2009 *Recommendation* represents a radical shift in regulatory policy, which may ultimately lead to the abolition of MTRs altogether. While the recent theoretical literature provides some qualitative support for this change in policy, in this paper we have provided a quantifiable approach to assessing the effects of significant reductions in MTRs in the UK mobile market, and elsewhere.

We show that reducing MTRs broadly in line with the European Commission's recommendation increases social welfare, consumer surplus and networks' profits in the UK fixed and mobile telephony markets. Depending on the strength of call externalities, social welfare may increase by as much as £700 million to £2.7 billion per year. In addition, contrary to claims made in the recent literature, our results confirm that reducing MTRs can also benefit mobile subscribers considered in isolation, especially when call externalities are significant. Our welfare analysis thus lends support to a move away from fully-allocated cost pricing and towards much lower MTRs, with bill-and-keep often resulting in the largest increase in overall welfare.

We have also analyzed the likely effects of the merger between Orange and T-Mobile and shown that its overall effect on welfare depends on the strength of call externalities, when MTRs are set at the their current, regulated levels. A prior adoption of bill-and-keep might have ameliorated these aggregate welfare effects, although serious concerns about the merger's negative impact on consumers remain. The undertakings agreed between the companies and the European Commission do not appear to address these concerns.

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Annex A Equilibrium Pre- and Post-Merger Outcomes

Call prices: In order to determine call prices, we follow the standard technique of finding the optimal pricing structure while holding market shares constant through an appropriate adjustment of the fixed fee. The equilibrium market shares will then be determined in a second step. This procedure is without loss of generality but simplifies the derivation of call prices.

Given uniform off-net prices, a non-merged firm i chooses the three prices p_{ii}, p_{ij} and p_{if}, while holding $\sum_{j\neq i}(w_i - w_j)$ constant by adapting F_i. Thus, using $dv_{ij}/dp_{ij} = -q_{ij}$ and $du_{ij}/dp_{ij} = p_{ij}q'_{ij}$, we have

$$\begin{aligned}\frac{dF_i}{dp_{ii}} &= M\alpha_i(\beta p_{ii}q'_{ii} - q_{ii}),\ \frac{dF_i}{dp_{if}} = -Nq_{if},\\ \frac{dF_i}{dp_{ij}} &= -M[(1-\alpha_i)\,q_{ij} + \alpha_i\beta p_{ij}q'_{ij}].\end{aligned}$$

Thus firm i's first-order conditions on profit-maximization become ($\bar{c}_{ij} = \sum_{l\neq i}\alpha_l c_{il}/\,(1-\alpha_i)$ is the average off-net cost)

$$\begin{aligned}0 &= \frac{d\pi_i}{dp_{ii}} = M^2\alpha_i^2\left(q_{ii} + (p_{ii} - c_{ii}) + \beta p_{ii}q'_{ii} - q_{ii}\right),\\ 0 &= \frac{d\pi_i}{dp_{ij}} = M^2\alpha_i\,(1-\alpha_i)\left(q_{ij} + (p_{ij} - \bar{c}_{ij})q'_{ij} - q_{ij} - \frac{\alpha_i}{1-\alpha_i}\beta p_{ij}q'_{ij}\right),\\ 0 &= \frac{d\pi_i}{dp_{if}} = MN\alpha_i\left(q_{if} + (p_{if} - c_{if})q'_{if} - q_{if}\right).\end{aligned}$$

The resulting call prices are

$$
\begin{aligned}
p_{ii} &= \frac{c_{ii}}{1+\beta},\ p_{if}=c_{if}, \\
p_{ij} &= \frac{\sum_{l\neq i}\alpha_l c_{il}}{1-(1+\beta)\alpha_i},\ j\neq i.
\end{aligned}
$$

The two merged firms (let us call them 1 and 2, and the merged network have market share $\alpha_{1+2}=\alpha_1+\alpha_2$), when maximizing joint profits $\pi_1+\pi_2$, will set the on-net prices p_{ii} and FTM price p_{if} above, thus we only have to determine the prices p_{12}, p_{21} and off-net prices p_{ij} $(j\geq 3)$. While it seems intuitive that calls between the two merged networks should be priced at on-net level, and off-net prices based on the joint market share, we will present the corresponding derivations because they are non-trivial. The merged network chooses its prices p_{12} and p_{1j} while adjusting F_1 and F_2 as to keep $\sum_{j\neq 1}(w_1-w_j)$ and $\sum_{j\neq 2}(w_2-w_j)$ constant (the determination of p_{21} and p_{2j} follows the same logic). Thus for calls between networks 1 and 2,

$$
\begin{aligned}
-(n-1)\left(M\alpha_2 q_{12}+\frac{dF_1}{dp_{12}}\right)-M\alpha_1\beta p_{12}q_{12}'+\frac{dF_2}{dp_{12}}&=0\\
(n-1)\left(M\alpha_1\beta p_{12}q_{12}'-\frac{dF_2}{dp_{12}}\right)+M\alpha_2 q_{12}+\frac{dF_1}{dp_{12}}&=0,
\end{aligned}
$$

which has solution

$$
\frac{dF_1}{dp_{12}}=-M\alpha_2 q_{12},\ \frac{dF_2}{dp_{12}}=M\alpha_1\beta p_{12}q_{12}',
$$

and for calls to other networks

$$
\begin{aligned}
-(n-1)\left(M\left(1-\alpha_{1+2}\right)q_{1j}+\frac{dF_1}{dp_{1j}}\right)+\frac{dF_2}{dp_{1j}}-(n-2)\,M\alpha_1\beta p_{1j}q_{1j}'&=0,\\
-(n-1)\frac{dF_2}{dp_{1j}}+\left(M\left(1-\alpha_{1+2}\right)q_{1j}+\frac{dF_1}{dp_{1j}}\right)-(n-2)\,M\alpha_1\beta p_{1j}q_{1j}'&=0,
\end{aligned}
$$

with solution

$$
\frac{dF_1}{dp_{1j}}=-M\left(\left(1-\alpha_{1+2}\right)q_{1j}+\alpha_1\beta p_{1j}q_{1j}'\right),\ \frac{dF_2}{dp_{1j}}=-M\alpha_1\beta p_{1j}q_{1j}'.
$$

That is, in both cases the adjustment in fixed fees exactly compensates for the change in surplus of subscribers on the originating and terminating network. The merged network maximizes $\pi_1+\pi_2$, which has first-order conditions (with $\tilde{c}_{1j}=\sum_{l\neq 1,2}\alpha_l c_{1l}/(1-\alpha_{1+2})$)

$$
\begin{aligned}
0 &= \frac{d\left(\pi_1+\pi_2\right)}{dp_{12}}=M^2\alpha_1\alpha_2\left[q_{12}+(p_{12}-c_{12})q_{12}'-q_{12}+(a_2-c_{t2})q_{12}'+\beta p_{12}q_{12}'\right],\\
0 &= \frac{d\left(\pi_1+\pi_2\right)}{dp_{1j}}=M\alpha_1\left[(1-\alpha_{1+2})\left(q_{1j}+(p_{1j}-\tilde{c}_{1j})q_{1j}'-q_{1j}\right)-\alpha_{1+2}\beta p_{1j}q_{1j}'\right]
\end{aligned}
$$

The resulting profit-maximizing call prices are

$$
p_{12}=\frac{c_{o1}+c_{t2}}{1+\beta},\ p_{1j}=\frac{\sum_{l\neq 1,2}\alpha_l c_{1l}}{1-(1+\beta)\,\alpha_{1+2}},
$$

with corresponding values for p_{21} and p_{2j}. That is, as expected calls between the merged networks are priced efficiently as on-net calls, while off-net call prices are set based on the merged networks' joint market share.

Subscription fees: We now determine the Nash equilibrium through networks' choice of subscription fee. First note from the market share equation (1) that the effect of fixed fees on market shares is given by

$$\frac{d\alpha_j}{dF_i} = -\sigma H_{ji}.$$

A non-merging firm i maximizes π_i, which has first-order condition

$$0 = \frac{d\pi_i}{dF_i} = -\sigma M H_{ii}\left(M\sum_{j=1}^{n}\alpha_j R_{ij} + Nq_i + F_i - f_i\right) + M\alpha_i\left(1 - \sigma M\sum_{j=1}^{n} H_{ji}R_{ij}\right),$$

or

$$F_i = f_i - Nq_i + M\sum_{j=1}^{n}\alpha_j\left(\hat{R}_{ij} - R_{ij}\right),$$

where we have defined the matrix $\hat{R} = (\hat{R}_{ij})_{n\times n}$ with

$$\hat{R}_{ii} = \frac{1}{\sigma M H_{ii}} - \sum_{j=1}^{n}\frac{H_{ji}}{H_{ii}}R_{ij},\ \ \hat{R}_{ij} = 0\ \forall\ j \neq i.$$

After the merger between firms 1 and 2, the first-order conditions for the non-merging firms remain unchanged. As concerns the merged firm, its first-order conditions for maximizing $\pi_1+\pi_2$ with respect to F_1 and F_2 can be expressed as

$$H_{11}x_1 + H_{21}x_2 = \frac{\alpha_1}{\sigma} - r_1,\ \ H_{12}x_1 + H_{22}x_2 = \frac{\alpha_2}{\sigma} - r_2,$$

where for $i = 1, 2$,

$$x_i = M\sum\nolimits_{k=1}^{n}\alpha_k R_{ik} + F_i + NQ_i - f_i,\ \ r_i = M\sum\nolimits_{k=1}^{n} H_{ki}\left(\alpha_1 R_{1k} + \alpha_2 R_{2k}\right).$$

The resulting fixed fees are again given by the above expression, where now

$$\begin{aligned}
\hat{R}_{11} &= \frac{\frac{H_{22}}{\sigma M} - \sum_{k=1}^{n}\left(H_{22}H_{k1} - H_{21}H_{k2}\right)R_{1k}}{H_{11}H_{22} - H_{21}H_{12}},\\
\hat{R}_{12} &= -\frac{\frac{H_{21}}{\sigma M} + \sum_{k=1}^{n}\left(H_{22}H_{k1} - H_{21}H_{k2}\right)R_{2k}}{H_{11}H_{22} - H_{21}H_{12}},
\end{aligned}$$

similar for $\hat{R}_{21}$ and $\hat{R}_{22}$, and $\hat{R}_{ij} = 0$ for all $i = 1, 2$ and $j \geq 3$, and $\hat{R}_{ii}$ as above for $i \geq 3$.

Annex B Calibration and Results with a Mobile Demand Elasticity of -0.3

This annex reports aggregate results for call externality parameters (β) of 0, 0.25, 0.5, 0.75 and 1, respectively, and for a demand elasticity of -0.3 for MTM calls. All reported results are stated in £m per calendar year in 2008/09 prices. Increases of the variables under consideration, as compared to the base scenario, (LRIC+) are given by positive values and decreases by negative values. In the tables below we have included the scenario of equal network preferences due to bill-and-keep (and thus equal equilibrium market shares) as "Bill-and-Keep (sym)". It is clear that consumer surplus would increase strongly with an equalization in market shares.

For $\varepsilon = -0.3$, we have found $a = 14.87$ and the following values of the demand slope depending on the strength of the call externality:

Table B.1 Demand slope

	$\beta = 0$	$\beta = 0.25$	$\beta = 0.5$	$\beta = 0.75$	$\beta = 1$
b	0.76	0.72	0.67	0.61	0.56

The demand parameters for mobile-to-fixed calls are $a_{mf} = 14.47$ and $b_{mf} = 3.71$, while those for fixed-to-mobile calls as the same as above. The calibrated values for the market differentiation parameter σ and its stability limits are:

Table B.2 Differentiation parameter

	$\beta = 0$	$\beta = 0.25$	$\beta = 0.5$	$\beta = 0.75$	$\beta = 1$
σ	0.000455	0.000451	0.000446	0.000440	0.000433
σ^{stab}	0.004995	0.003936	0.003192	0.002608	0.002119

Aggregate effects. The following three tables describe aggregate changes in welfare, consumer surplus and profits.

Table B.3a Change in Welfare Over "LRIC+" Pricing

	$\beta = 0$	$\beta = 0.25$	$\beta = 0.5$	$\beta = 0.75$	$\beta = 1$
Pure LRIC	569	811	1084	1399	1773
Reciprocal with Fixed	601	861	1153	1489	1886
Bill-and-Keep	612	879	1178	1522	1927
Bill-and-Keep (sym)	1130	1409	1723	2083	2510

Table B.3b Change in Consumer Surplus Over "LRIC+" Pricing

	$\beta = 0$	$\beta = 0.25$	$\beta = 0.5$	$\beta = 0.75$	$\beta = 1$
Pure LRIC	-200	-7	207	447	725
Reciprocal with Fixed	-267	-59	170	426	720
Bill-and-Keep	-299	-86	148	410	711
Bill-and-Keep (sym)	1491	1705	1941	2204	2507

Table B.3c Change in Profits Over "LRIC+" Pricing

	$\beta = 0$	$\beta = 0.25$	$\beta = 0.5$	$\beta = 0.75$	$\beta = 1$
Pure LRIC	769	818	877	952	1048
Reciprocal with Fixed	868	920	984	1063	1166
Bill-and-Keep	912	965	1030	1111	1216
Bill-and-Keep (sym)	-361	-297	-218	-121	3

Mobile telephony. The following three tables describe the changes in welfare, consumer surplus and profits in the mobile market considered in isolation.

Table B.4a Change in Mobile Welfare Over "LRIC+" Pricing					
	$\beta = 0$	$\beta = 0.25$	$\beta = 0.5$	$\beta = 0.75$	$\beta = 1$
Pure LRIC	-219	23	296	611	985
Reciprocal with Fixed	-305	-45	247	583	980
Bill-and-Keep	-346	-80	219	563	968
Bill-and-Keep (sym)	172	450	764	1125	1551

Table B.4b Change in Mobile Consumer Surplus Over "LRIC+" Pricing					
	$\beta = 0$	$\beta = 0.25$	$\beta = 0.5$	$\beta = 0.75$	$\beta = 1$
Pure LRIC	-463	-269	-56	185	462
Reciprocal with Fixed	-569	-361	-132	124	418
Bill-and-Keep	-619	-406	-171	91	391
Bill-and-Keep (sym)	1172	1386	1621	1885	2187

Table B.4c Change in Mobile Profits Over "LRIC+" Pricing					
	$\beta = 0$	$\beta = 0.25$	$\beta = 0.5$	$\beta = 0.75$	$\beta = 1$
Pure LRIC	244	292	352	427	523
Reciprocal with Fixed	264	316	380	459	562
Bill-and-Keep	272	326	391	472	577
Bill-and-Keep (sym)	-1000	-936	-857	-760	-636

Fixed telephony. The following table describes the changes in welfare, consumer surplus and profits in the fixed telephony market.

Table B.5 Change Over "LRIC+" Pricing			
	Welfare	Consumer Surplus	Profits
Pure LRIC	788	263	525
Reciprocal with Fixed	906	302	604
Bill-and-Keep	959	320	639
Bill-and-Keep (sym)	959	320	639

Annex C Efficiency Gains from the Orange/T-Mobile Merger[57]

Orange and T-Mobile forecast efficiency gains totalling £545m a year from 2015 onwards.[58] However in the preceding years 2010 to 2014, forecast annual gains are generally lower than this due to implementation costs and the phasing-in of savings. Orange and T-Mobile forecast:

- annual operating expenditure (opex) savings of £445m from 2014 onwards;
- the phasing-in of opex savings at 15% of £445m in 2010, 75% of £445m in 2012, and 100% of £445m in 2014;
- opex integration costs to net off these savings totalling between £600m and £800m between 2010 and 2014;
- annual net capital expenditure (capex) savings of £100m from 2015 onwards;
- total net capex savings of £620m between 2010 and 2014; and
- a Net Present Value (NPV) of over £3.5bn in net savings.

We have used this information to estimate the equivalent level annuity which would match these efficiency gains, i.e. a constant per annum net saving which delivers the same NPV as the variable profile of savings described above.

We do not know the forecasting horizon over which the NPV of £3.5bn has been calculated, nor do we know some of the detailed cashflow assumptions used to calculate that NPV (e.g. phasing of opex savings in 2011, precise level of integration costs). We have therefore developed a range of annuity estimates for each of two assumed forecasting horizons: 25 years and 100 years. In each case, we have calculated the level annuity equivalent to a high gain scenario, where the detailed assumptions are assumed to deliver relatively high gains within the envelope provided by the available information (e.g. opex savings in 2011 assumed at 50% of £ 445m, integration costs assumed at £600m); and a low gain scenario at the other extreme (e.g. opex savings in 2011 assumed at 30% of £ 445m, integration costs assumed at £800m).

For each scenario, we have calculated the discount rate that would generate an NPV of £3.5bn for the given forecasting horizon and set of detailed assumptions, and then calculated the level annuity which, over that same forecasting horizon, would also generate an NPV of £3.5bn.

Our results are shown below:

Equivalent level annuity (£m)	High gain	Low gain
25 year horizon	410	388
100 year horizon	419	399

[57] We are grateful to Adam Mantzos for preparing this annex.

[58] All figures sourced from the presentation, *Combination of Orange UK & T-Mobile UK: Creating a new mobile champion*, Orange and T-Mobile, 8 September 2009.

Annex D Merger Analysis with a Mobile Demand Elasticity of -0.3

All reported results are stated in £m per calendar year in 2008/09 prices. Increases of the variables under consideration are given by positive values and decreases by negative values.

Effects of the Merger under 2010/11 MTRs. Table D.1 reports the changes in welfare, consumer surplus and profits due to the merger if MTRs are kept at their 2010/11 values.

Table D.1 Merger with 2010/11 MTRs

	$\beta = 0$	$\beta = 0.25$	$\beta = 0.5$	$\beta = 0.75$	$\beta = 1$
Change in Welfare	-34	-50	-129	-404	—
Change in Consumer Surplus	-949	-903	-865	-855	—
Change in Profits	915	852	736	451	—

Effects of the Merger with Lower MTRs. Table D.2 describes the changes in welfare, consumer surplus and profits due to the merger if pure LRIC had been introduced before the merger.

Table D.2 Merger under Pure LRIC

	$\beta = 0$	$\beta = 0.25$	$\beta = 0.5$	$\beta = 0.75$	$\beta = 1$
Change in Welfare	-70	-70	-72	-85	-127
Change in Consumer Surplus	-1138	-1127	-1117	-1106	-1093
Change in Profits	1068	1057	1044	1022	966

Table D.3a describes the changes in welfare, consumer surplus and profits due to the merger if bill-and-keep had been introduced before the merger.

Table D.3a Merger under Bill-and-Keep

	$\beta = 0$	$\beta = 0.25$	$\beta = 0.5$	$\beta = 0.75$	$\beta = 1$
Change in Welfare	-71	-71	-71	-73	-81
Change in Consumer Surplus	-1166	-1160	-1158	-1156	-1154
Change in Profits	1094	1090	1087	1084	1072

Finally, Table D.3b describes the changes in welfare, consumer surplus and profits due to the merger under bill-and-keep and symmetric network preferences.

Table D.3b Merger under Bill-and-Keep with Preference Symmetry

	$\beta = 0$	$\beta = 0.25$	$\beta = 0.5$	$\beta = 0.75$	$\beta = 1$
Change in Welfare	-23	-23	-24	-26	-31
Change in Consumer Surplus	-1060	-1056	-1054	-1054	-1055
Change in Profits	1037	1032	1030	1028	1024