Welfare Effects of Alternative Approaches to Regulating Call Termination Rates in the UK Mobile Market

A Report for H3G UK

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Executive Summary

This report presents the results of a calibrated model for the market for mobile telephony in the UK, with the inclusion of calls from and to the fixed network. The model includes five networks with realistic market shares and considers the resulting imperfectly competitive equilibrium. The analysis is focussed on the short-run effects of different levels of mobile termination charges on total welfare, consumer surplus and profits.

Our simulations using the calibrated model indicate that lowering mobile termination rates below "LRIC+" to either "LRMC",[1] reciprocity at the cost of termination with the fixed network, or Bill & Keep (zero termination rates), increases social welfare, consumer surplus and networks' profits. Clearly mobile termination is not a "zero-sum" game because the level of mobile termination rates has a real effect on market allocations.

Depending on the scenario, in particular the strength of the call externality, social welfare related to mobile and fixed telephony is found to increase by the equivalent of about £100m to £1.1bn per year. If call externalities (a measure of the utility of receiving calls) are weak then aggregate consumer surplus may decrease, but if they are strong then aggregate consumer surplus increases by up to about £600m. Total profits of fixed and mobile networks increase by between £160m and £600m, of the former due to the reduction in transfers, and of the latter due to reduced network effects.

Thus our simulations lend support to a move away from "LRIC+" towards lower MTRs, with Bill & Keep consistently leading to the highest increase in welfare.[2]

In the medium to long run, these lower MTRs on existing networks allow small networks to grow and invite more entry. Therefore they will lead to a more competitive market and additional benefits in terms of higher welfare and higher consumer surplus.

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1 A note on the terminology adopted in this report: "LRIC+" and "LRMC", as used by Ofcom, are referred to by the European Commission as "FAC" (fully allocated cost) and "LRIC", respectively, and by H3G in its submission to the Consultation as "AT-LRIC+" (All Traffic LRIC+) and "CT-LRIC" (Call Termination LRIC).

2 We did not consider Capacity Based Charges in our simulations.

1 Introduction

1. European regulators have recently been debating the merits and demerits of different approaches to regulating mobile termination rates (MTRs). Until now, the approach adopted by Ofcom in the UK, and by most other European regulatory authorities, has been to allow for total cost recovery based on fully allocated cost models.[3] 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. Impetus for change has also come from the experiences of new entrant networks in many European countries, which have struggled to gain market share in the face of high MTRs, and the significant levels of on-net/off-net price discrimination adopted by incumbent mobile network operators (MNOs).[4]

2. In May 2009, the European Commission (2009a) issued a Recommendation which sets out its views on how national regulators, such as Ofcom, should approach these issues in future. The Commission recommends dramatic reductions in MTRs to reflect the actual incremental costs of providing voice call termination services to third parties.[5] The Commission's Recommendation and accompanying documents (EC 2009b; 2009c) reflect much of this new economic thinking and experience. In particular, the Commission (2009b) has noted that:

> "*Above-cost termination rates can give rise to competitive distortions between operators with asymmetric market shares and traffic flows. Termination rates that are set above an efficient level of cost result in higher off-net wholesale and retail prices. As smaller networks typically have a large proportion of off-net calls, this leads to significant payments to their larger competitors and hampers their ability to compete with on-net/off-net retail offers of larger incumbents. This can reinforce the network effects of larger networks and*

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3 See Harbord and Pagnozzi (2008) for a detailed description of Ofcom's approach to determining "cost-based" MTRs.

4 See e.g. DeGraba (2003); Jeon, Laffont and Tirole (2004); Armstrong and Wright (2007); Berger (2004) (2005); Hoernig (2007); Hermalin and Katz (2006); Calzada and Valletti (2008); Cabral (2009); Hoernig (2008). Harbord and Pagnozzi (2008) provide a survey of much of this literature.

5 This reduction is implemented essentially by no longer allowing costs which are common between services to be recovered from termination charges. According to the EC, this could result in a decrease in average rates in Europe from above 8 cpm to as low as 2.5 cpm by 2012. The actual (short-run) marginal costs of termination, to which academic models of network competition usually refer, will still be somewhat lower, since the EC's proposed "cost increment" still includes the fixed cost of providing the additional capacity needed to supply termination of incoming calls from other networks.

*increase barriers to smaller operators entering and expanding within markets." (*p. 16)

"It has been further indicated in recent economic literature that in the presence of call externalities mobile networks have strong incentives to implement on-net/off-net price differentials due to: (i) high mobile-to-mobile termination charges which exceed marginal costs; and (ii) their strategic incentives to reduce the number of calls that subscribers on rival networks receive, reducing the attractiveness of rival networks and hence their ability to compete. This theory suggests that mobile call termination charges above marginal costs can lead to permanent net payments by smaller networks and, since off-net prices are set above costs, also implies that smaller networks receive relatively fewer calls. According to some of this literature, termination charges which are above the marginal costs of termination result in strategically-induced network effects which may be detrimental to smaller networks. " (p. 18)

"Call termination services are two-sided, with the network(s) being the platform and the caller and receiver being on either side of that platform. The demand elasticities on either side of the platform mean that the structure of prices impacts on the levels of consumption; therefore, it often plays a crucial role in bringing the two sides of the market together." (p. 29)

3. Following the recent EC Recommendation, Ofcom has issued a consultation document which broadly reconsiders the pros and cons of a number of alternative approaches to regulating MTRs. Apart from the alternative of total deregulation, which seems an unlikely choice, Ofcom is consulting on five possible regulatory options:[6]

    1) *Long Run Incremental Cost + (LRIC+)* – a charge control set broadly on the basis of the same cost standard as it is today.

    2) *Long Run Marginal Cost (LRMC)* – revised charge control methodology with no allowance for the recovery of costs common between termination and other services, broadly the approach recommended by the EC.

    3) *Capacity Based Charges (CBC)* – a different approach to setting the structure of termination charges based on the capacity required for termination.

    4) *Mandated Reciprocity* – setting mobile termination charges to match the rates set for fixed operators.

6 As mentioned above, "LRIC+" and "LRMC", as used by Ofcom, are referred to by the European Commission as "FAC" (fully allocated cost) and "LRIC", respectively, and by H3G in its submission to the Consultation as "AT-LRIC+" (All Traffic LRIC+) and "CT-LRIC" (Call Termination LRIC). Since this report responds to Ofcom's Consultation, here we adopt Ofcom's terminology.

5) *Mandated "bill and keep" (B&K)* – termination charges effectively set at zero.

4. Option 1 is the status quo, an approach which has now essentially been rejected in the EC's Recommendation, while Option 2 is the EC's recommended approach. Option 3 is consistent with Options 1, 2 or 5 depending on how capacity charges are determined (with the latter option involving a zero capacity charge), but recognizes that most, if not all, costs associated with providing mobile termination services are fixed or common between termination minutes, and would possibly not be correctly reflected by the pence (or cent) per minute charges allowed for in regulated MTRs (see Harbord and Pagnozzi 2008; Quigley and Vogelsang 2003; Calzada 2007). Option 4 would dramatically reduce MTRs, since fixed line operators' regulated termination rates are typically an order of magnitude below those charged by mobile networks. Option 5 effectively abolishes MTRs altogether, and is the approach adopted in a number of countries such as the USA, Canada, Hong Kong and Singapore (see Analysys Mason 2008).

5. Ofcom's current consultation document discusses the pros and cons of these various alternative approaches within a framework which considers, in a purely qualitative and largely informal way, such criteria as "e*conomic efficiency"; "distributional effects on consumers"; "competitive impacts";* and "*commercial and regulatory consequences*". While Ofcom (2007, Annex 19), reports the results of a welfare analysis which was intended to provide "*an order of magnitude indication of the consumer welfare gain from regulating MCT charges*", as Ofcom itself recognises (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 unsuited to the task of estimating the welfare gains from reducing MTRs.

6. The EC's Recommendation is 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 EC's Recommendation is broadly consistent with the conclusions which seem to emerge from this new literature.

7. Section 4 and Annex of EC (2009c) provide the Commission staff's own estimate of the welfare effects of following the Recommendation, as compared to persisting with the present process of reductions of termination rates until

2011. This calculation is performed at an aggregate level for the whole of the European Union, and proceeds as follows: i) EU-wide ARPM (average revenue per minute) is calculated and used as a proxy for the mobile call price per minute, independently of call destination and type of tariff; ii) a certain percentage of the MTR reduction is assumed to be "passed through" into lower call ARPM on mobile networks, and a lower price of calls to mobile networks from the fixed network, which then gives rise to an increase in respective call volumes; iii) the resulting changes in profits and consumer surplus are computed. The overall welfare effect over 2007 – 2012 for the whole of the EU is found to be at most 1 bn Euros, if not slightly negative.

8. As with Ofcom's 2007 model, this computation is incapable of capturing the effects of call externalities, imperfect competition and industry dynamics. By its very nature, it also neglects national specificities, such as the degree of competition (which may affect pass-through), asymmetries between operators, and the nature of tariffs in mobile telephony.

9. What is lacking, therefore, is a realistic quantitative assessment of the welfare consequences of adopting one or another of the alternatives now being aired, while taking into account all of these factors. Our purpose in this report is to provide such an assessment for the UK mobile market based on the standard model used by all economists to analyze competition, pricing and welfare in network markets such as mobile telephony. In particular we estimate the impact on total welfare, consumer surplus and producer surplus of a decrease in MTRs in the UK market from their current regulated levels to: (i) "LRMC" (or LRIC in the EC's nomenclature); (ii) reciprocal rates with the fixed network; and (iii) zero, or "bill and keep" for MTM and FTM rates.

10. The key ingredients required for such an analysis are: (A) an appropriate equilibrium theory of the determination of mobile-to-mobile retail call charges, so that imperfect competition, or competitive interaction between a number of asymmetrically-sized MNOs, can be captured; (B) reasonable estimates of the marginal (or avoidable) costs of call origination and termination; (C) the inclusion of calls from and to the fixed network; and (D) allowance for the effects of call externalities, which are crucial determinants of competition between mobile networks and economic welfare.

11. Our quantitative analysis is based on Hoernig (2009), which provides an analytically tractable model of competition between multiple, asymmetrically-

sized mobile networks and allows us to determine both consumer surplus and networks' profits in the imperfectly competitive equilibrium.[7]

2 A short description of the market model

2.1 Assumptions

12. While in Annex B we will set out the market model in detail, in the present section we will provide a brief outline of its structure and assumptions.

13. **Mobile networks:** There are five mobile networks of different size and one fixed network. Networks face a given fixed cost per subscriber and given constant marginal costs for originating and terminating calls. All networks are interconnected and terminate incoming calls at a price given by their respective mobile termination rate (MTR). Consumers perceive networks as providing differentiated services, thus we consider a market equilibrium under imperfect competition.

14. **Mobile tariffs:** Mobile networks offer their retail customers bundles of mobile access, on-net calls and off-net calls (to other mobile networks and the fixed network). They charge multi-part tariffs consisting of a subscription fee, plus per-minute prices for on-net calls to the same network, for off-net calls to other mobile networks (MTM calls), and for off-net calls to the fixed network (MTF calls).[8]

15. In this model 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.[9] Therefore, for simplicity and robustness of our modelling, we have adopted the conservative stance that this interaction does not matter for our results.

16. On the fixed network, we only consider calls to mobile networks (FTM calls) and the reception of calls from mobile customers (MTF calls), as demand for these calls does not strongly interact with the other types of calls offered by

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7 Hoernig (2008) contains many of the ingredients of this analysis but considers only duopoly networks with no allowance for fixed-to-mobile and mobile-to-fixed calls.

8 As set out below in Section 3, using multi-part tariffs for these simulations implies adopting a "worst-case scenario" in terms of the effect of lower MTRs on mobile consumer surplus. Thus our simulations likely underestimate mobile users' surplus.

9 Furthermore, in recent years the corresponding cross-elasticities of demand are considered to have been small (see Ofcom 2007, paragraph A19:16).

fixed networks, apart possibly from calls between fixed numbers (FTF calls). The latter are a substitute for calls to FTM calls whenever the mobile call receiver is also contactable through a fixed line. Lower MTRs and FTM prices will then cause an increase in FTM calls and a decrease in FTF calls. This is inefficient to the extent that the network cost of mobile termination is higher, but increases welfare as more calls are picked up. The total welfare effect of this type of call substitution is therefore ambiguous.

17. The fixed network sets a fixed-to-mobile call price equal to the (weighted) average of MTRs plus a fixed amount, its "retention". The latter covers origination cost and provides some additional call revenue. Thus we assume full pass-through of changes in MTRs to fixed-to-mobile call prices.

18. **Consumers:** There is a given number of customers on each mobile network and on the fixed network.[10] Each customer makes calls to all other potential recipients on fixed and mobile networks with a given probability (in other words, we assume an *ex ante* balanced calling pattern), but call demand differs between clients of mobile networks and the fixed network.

19. Networks' customers receive utility from making calls, as a function of call length and the number of calls made. They also obtain utility from receiving calls (there is a "call externality"),[11] independently of their origin. A single consumer's surplus resulting from a specific tariff is then given by his utility of making and receiving calls minus the subscription fee. Each consumer makes his choice of network based on his own personal preferences for specific networks and the surplus resulting from the tariffs on offer.

20. **Market equilibrium:** We model the imperfectly competitive market outcome that will result from mobile networks' offering tariffs such that no single network would like to change its offer given the other offers.[12] This is the standard competitive equilibrium concept used in Economics for modelling market outcomes. The equilibrium outcome determines call prices, subscription fees and the resulting consumer surplus and network profits.

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10 On the one hand, Ofcom's value indicated for the subscription elasticity is low, and on the other, as argued below in Section 3, marginal subscribers, who predominantly use pre-paid tariffs, will be less subject to increases in bundle prices. Therefore the assumption of inelastic subscription is not likely to strongly bias our results.

11 This is a feature recently introduced in the academic literature, see e.g. Jeon, Laffont and Tirole (2004); Armstrong and Wright (2007); Berger (2004) (2005); Hoernig (2007); it is realistic and has significant effects on how networks compete.

12 Evidently, this is the notion of "Nash equilibrium" in Game Theory.

21. **Welfare:** Total welfare is given by the sum of total consumer surplus and profits, for both the mobile and fixed telephony market. On a fundamental level, here transfers between consumers and firms cancel out, and what remains is the relationship between the surplus created from making and receiving calls and the underlying network cost.

22. A word of caution: The estimation of *absolute* values for welfare and consumer surplus is fraught with substantially more uncertainty than the measurement of *differences* in these variables between scenarios. Therefore we would like to stress that the most reliable outputs of our model are the effects of changes to a given base scenario, and not the computed absolute values.[13]

23. **Time frame:** In this implementation of the model, we keep the number of mobile networks, their market shares, and overall subscriber numbers in both markets, fixed in order to portray the short-run effects of changes in mobile termination rates. These short-run effects are changes in call prices and demand, the impact of network effects on competitive intensity and resulting changes in subscription fees.

24. In the medium to long term, changes to mobile termination rates and the ensuing network effects will lead to adjustments in the very structure of the market. First, lower MTRs will lead to lower off-net prices and smaller tariff-mediated network effects. This will make smaller networks more attractive to consumers and therefore lead to further convergence in market shares, better exploitation of returns to scale and lower cost of calls.[14] As a result, the medium-run welfare effect of lower termination rates is probably under-estimated by our short-run model.[15]

25. Second, the reduction in tariff-mediated network effects due to lower off-net prices makes it easier for small networks and/or mobile virtual network operators (MVNOs) to enter and compete effectively in the market. Thus

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13 This is so because the calibration of demand functions is commonly based on the elasticity of demand at a specific data point. Essentially, simulated values for welfare and consumer surplus in different scenarios differ from the "true ones" roughly by the same (unknown) constant, which cancels out when only differences are considered.

14 More precisely, additional consumers can be served at lower marginal cost on small networks than on large ones since the latter face additional investments to provide the necessary capacity.

15 Hoernig (2009) goes half-way by solving explicitly for equilibrium market shares while maintaining constant consumer perceptions about mobile operators' relative attractiveness.

lower MTRs on existing networks may increase the number of competitors and the degree of competitiveness in the long run.

26. Third, lower mobile termination rates tend to lead to lower fixed-to-mobile prices and consumers substituting MTM calls by FTM calls. Since this happens as a result of free choice by consumers, and since calls originated on the fixed network incur lower network costs, both consumer surplus and total welfare should increase further. Again, our short-run model tends to underestimate this effect of lower MTRs.

2.2 Calibration

27. The details of the calibration are described in Annex A, and are mostly equal to Market Analysis (2008). We have used data from Ofcom (2007), Annex 19, to calibrate network cost, subscriber cost and demand on both mobile and fixed networks.

28. In the base scenario, which portrays option 1) in Ofcom's consultation, MTRs are set at Ofcom's "LRIC+" levels, 4.5 ppm for H3G and 4.2 ppm for the other MNOs (based on the final values set by the CC/CAT appeal of 4.3 ppm and 4.0 ppm, indexed by 5.5% inflation to increase from 2006/07 prices to 2009/10 prices). This base scenario is compared with three other scenarios, corresponding to: "LRMC", where MTRs are set equal to marginal cost; reciprocal MTRs set at the cost of termination on the fixed network; finally, Bill & Keep.

29. In the simulations, the parameter measuring the intensity of call externalities is varied between five levels: zero (no call externality), the intermediate values of 0.25, 0.5 and 0.75, and the maximal values of 1 (receiving a call results in the same utility as making one). Arguably, values of at least 0.5 are realistic, since most calls that consumers receive are not nuisance calls and usually receivers of calls do not unilaterally hang up.

30. We also consider three different sets of values for the marginal cost of originating and terminating calls on mobile networks. These are based on the CT-LRIC ("LRMC") estimates submitted by H3G to this Consultation of 0.5 ppm and 1.0 ppm; plus an upper bound sensitivity for CT-LRIC of 2.0 ppm[16].

16 The marginal cost of origination might differ slightly from the marginal cost of

3 Economic Effects

31. In this section we present a short overview of main economic effects linked to termination pricing. These effects differ significantly between the two cases of fixed-to-mobile calls and mobile-to-mobile calls.

3.1 Fixed-to-mobile interconnection and the waterbed effect

32. The perceived marginal cost of a fixed-to-mobile call faced by the fixed network operator is composed of the marginal cost of origination on the fixed network and the MTR of the mobile network that is being called. Since the latter has commonly been much higher than the former, the MTR is the principal cost component of an FTM call. If the fixed network sets its retail price for FTM calls as MTR plus a fixed retention to cover the marginal cost of origination, then the MTR feeds directly through to the FTM call price. A high MTR then leads to a high FTM call price and a reduction in the number and/or duration of these calls.

33. The efficient quantity of FTM calls is determined by the level of marginal cost at the originating and terminating end and the extent of uninternalized call externalities, i.e. the utility of receiving calls. If call receivers gain no utility from answering calls, as was assumed in the earlier academic literature,[17] then the efficient amount of calls is made when the price of calls is set equal to the sum of marginal costs of originating and terminating calls. In the presence of call externalities, the efficient amount of calls is caused by a FTM call price which is below marginal cost and internalizes the call externality between customers on the fixed network and on mobile networks. While in the former case the efficient MTR would be equal to the marginal cost of termination, in the latter it is below the marginal cost of termination.

34. An MTR above the marginal cost of termination definitely distorts the quantity of FTM calls downwards and therefore reduces welfare in the fixed telephony market. If call externalities are taken into account, then this distortion is even larger. Furthermore, it extends into the mobile market because of the inefficiently low quantity of calls received from the fixed network.

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termination but the difference is unlikely to be material.

[17] Under this assumption there is no reason why someone would answer their phone, or leave it on to receive calls, thus it is highly unrealistic.

35. A different question is what happens to the net gain that mobile networks derive from terminating calls from the fixed networks at an MTR above marginal cost. In most economic models, which consider network cost as exogenous, all or most of these gains are "handed over" to clients of mobile networks as a result of competitive forces in the mobile market. That is, competition for consumers makes mobile networks spend FTM profits as part of their "war chest", as has also been confirmed by empirical analysis.[18] [19] This phenomenon has been dubbed the "waterbed effect", and essentially amounts to a transfer of surplus from clients of the fixed networks to clients of mobile networks.

36. Economic theory predicts that the waterbed effect is strongest with multipart-tariffs involving a subscription payment, since in this case the equilibrium subscription fees directly respond to changes in termination profits. In this setting, networks' profits will be neutral to MTR values in FTM interconnection.

37. With linear tariffs, i.e. tariffs that only charge per minute but do not involve a subscription fee, the waterbed effect is found to be less strong,[20] i.e. mobile networks retain some or most of the FTM termination profits instead of passing them on to consumers. As linear tariffs are more akin to pre-paid tariffs, which are typically taken up by less intensive or marginal users of mobile telephony, these latter users will be less strongly affected by the waterbed effect than clients with post-paid contracts. Rather, reductions in MTRs will reduce networks' profits.

38. It is sometimes argued that pre-paid tariffs are usually not linear since they can involve handset subsidies (basically, a negative fixed fee). We believe that most pre-paid tariffs are essentially linear for three reasons: 1) Many pre-paid tariffs simply do not involve handset subsidies; 2) if they do, pre-paid tariffs tend to come with low-end handsets, who are sold at a price not far from cost; 3) per-minute call prices tend to be high as compared to post-paid tariffs, so that overall expenditure is mostly driven by usage.

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18 See Genakos and Valletti (2009). The existence of this effect has also been accepted by the Competition Commission in the appeal of Ofcom's 2007 review: see paragraphs 4.55 to 4.60, *Mobile phone wholesale voice termination charges – Determination*, Competition Commission, 16 January 2009.

19 An alternative line of argument, which we will not pursue here, holds that if MTRs were set at cost then networks' incentives to reduce cost would be strengthened. Over time this would lead to lower prices, reducing the waterbed effect.

20 See Hoernig (2009).

39. Thus one should expect heavy users' post-paid tariffs to be more strongly affected by the waterbed effect, for example through higher subscription fees, lower handset subsidies or lower quality of subsidized handsets, than marginal users' pre-paid tariffs. This should limit the potential reduction in mobile subscribers due to higher prices.

40. The effect of lower MTRs on all mobile networks derived from our model, considering for now only FTM calls, can then be described as follows:

    1) Lower FTM retail prices for consumers on the fixed network, thus more call minutes and more consumer surplus;

    2) Higher profits on the fixed network due to the increase in call minutes if the fixed network's absolute margin per call changes little;

    3) Smaller termination payments from fixed to mobile networks, and as a result higher prices in the mobile market. This effect is likely to be stronger on subscription fees in post-paid tariffs than on call prices in pre-paid tariffs.

    4) Lower profits on mobile networks, with a relatively small effect related to post-pay tariffs (because there the waterbed effect tends to be strong), and a larger effect related to pre-pay tariffs.

    5) Larger utility of mobile customers from receiving FTM calls due to the increase in FTM call minutes.

41. Thus the fixed network and its clients are better off, mobile networks are worse off as long as the waterbed effect is not full, i.e. not all of FTM termination profit is passed on to consumers, while clients of mobile networks are subject to two opposing effects.

3.2 Mobile-to-mobile interconnection and network effects

42. Mobile termination rates have different effects when instead of FTM calls MTM calls (between mobile networks) are considered. First of all, MTRs have no direct effect on the pricing of on-net calls, since their price is optimally set by taking into account the relevant marginal costs of on-net origination and on-net termination, and where applicable call externalities – MTRs do not enter the equation.

43. Under the CPP (calling party pays) system, the MTR level is decisive, though, for the pricing of off-net calls to other networks, as the two cost elements that the originating network faces are precisely its marginal cost of origination and the MTR of the terminating network. Thus the direct effect of lower MTRs is lower off-net prices, where the "pass-through", i.e. the price reduction relative to the MTR reduction, depends on how costs are reflected in off-net prices. These lower prices then lead to higher call quantities and increase total welfare. How much of the total increase in welfare due to MTRs being lowered towards the efficient level will actually be retained by consumers depends on how the pricing of the total service bundle changes with lower MTRs. In particular, in multi-part tariffs the subscription fee will likely be adjusted upwards, as we explain further below in this section.

44. A second important feature of MTRs in MTM interconnection is the creation of "tariff-mediated network effects". Higher off-net prices caused by high MTRs not only reduce the number of off-net calls, they also indirectly affect the nature of competition in mobile telephony. This is so because the presence of high off-net prices (in the presence of efficiently set low on-net prices) means that consumers prefer to make on-net calls rather than call someone on a different network. Networks therefore strive to increase their user base in order to become even more attractive – i.e. create positive network effects. With multi-part retail tariffs, this increased competition for subscribers actually benefits consumers because they will be offered more attractive service bundles (which include higher off-net prices but an even lower subscription fee).

45. On the other hand, linear tariff bundles (more akin to pre-paid tariffs) become less expensive with lower MTRs in mobile-to-mobile interconnection. Even though on-net prices may increase to some extent, the decrease in off-net prices dominates the on-net effect. Only considering MTM calls, economic theory predicts that lowering MTRs will lead to more expensive bundles in the post-paid segment and cheaper bundles in the pre-paid segment.

46. A further important consequence of tariff-mediated network externalities is that recent entrants into mobile telephony find it hard to grow their subscriber base in the presence of strong tariff-mediated network effects, because consumers will prefer joining large networks. Lower MTRs on all networks then allow recent entrants to charge low off-net prices to other networks and benefit from reduced network effects.

47. Thus contrary to what has been affirmed in EU (2009c), MTM termination is not a "zero-sum game":[21] While gains and losses due to money transfers between networks do indeed cancel out in aggregate, there are real effects of MTR levels on call quantities and network effects. While the former affect consumers and total welfare, independently of whether MTRs are profit-neutral or not, the latter impact the competitiveness of the market and the facility of entry.

48. As concerns allocative efficiency, or the effect on total welfare of MTR in mobile-to-mobile calls, in the absence of call externalities, the latter is maximized if all calls are priced at their respective marginal network cost, i.e. if MTRs are equal to the marginal costs of termination. If call externalities are significant, though, then as with fixed-to-mobile calls the efficient call price internalizes the call externality and is below cost. This implies that the relevant MTR should be set below the marginal cost of termination.

49. It has been wrongly claimed that consumers can internalize call externalities by joining the same network. When doing so they internalize tariff-mediated network effects but not call externalities, since in this case consumers merely adjust their calling pattern to the tariff structure. On the other hand, the internalization of call externalities occurs when call originators determine the length of their calls not only taking into account their own utility but also the utility of the receiving side, independently of whether caller and called are on the same network or not. The resulting calls will be longer and/or more frequent than one would predict otherwise. Furthermore, one should expect that caller and called will take turns in making these longer calls, which indicates that one should expect this internalization to happen between close acquaintances only. Thus the internalization or not of call externalities has not much to do with network choice as such (while it may exist in parallel with coordinated network choice), but rather refers to the determination of call length or frequency. Its extent is largely an as yet (to our knowledge) unexplored empirical question. The upshot is that call externalities can be expected to be neither insignificant nor fully internalized.

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21 Roughly speaking, zero-sum games are interactions where the different actors' gains and losses cancel out in aggregate.

3.3 Aggregate economic effects

50. Considering both the markets for fixed and mobile telephony together, it is clear that changing MTRs from Ofcom's "LRIC+" to "LRMC" or to even lower values such as reciprocity with fixed network or Bill & Keep increases total welfare because it reduces or eliminates the misallocation of FTM and MTM calls caused by MTRs that are too high.

51. As concerns consumer surplus, to the extent that the waterbed is effective, lower MTRs lead to reduction in the transfer of surplus from the clients of the fixed network to those of mobile networks. Holding call quantities constant, these transfers as such do not change aggregate consumer surplus, only its distribution. On the other hand, over and above the changes in transfers, consumer surplus on the fixed market will increase due to lower FTM prices, and consumer surplus on the mobile market will decrease in the post-pay segment and increase in the pre-pay segment due to the reduction in tariff-mediated network externalities. Thus aggregate consumer surplus increases with the move to lower MTRs unless the effect on post-pay contracts dominates the effect on pre-pay contracts and on the fixed network.[22]

52. With multi-part tariffs, economic theory predicts that profits on the fixed and mobile networks increase, because of lower transfers from the fixed network to mobile networks (which end up with their clients due to a strong waterbed effect), and because of the reduction in tariff-mediated network externalities. On the other hand, if linear tariffs are prevalent then lower MTRs imply lower profits for mobile networks due to the weaker waterbed effect (networks retain part of FTM profits) and the increased competitiveness of the mobile market in the pre-paid segment.

53. Bill & Keep is unlikely to be exactly welfare-maximizing when only the above arguments are taken into account, because in this framework a zero interconnection charge has no special meaning. However, given the result that efficient MTRs are likely to be set at or below marginal cost, B&K has a fair chance of resulting in higher welfare than MTRs based on fully allocated cost or any other cost concept that exceeds marginal cost.

54. Furthermore, B&K, as compared to other MTR values, reduces regulatory and transaction costs: No information on actual cost values is needed, ending the

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22 Actually, our simulation only considers multipart tariffs, which implies a worst-case scenario in terms of consumer surplus (but higher profits) in the mobile market. Still, even in this case aggregate consumer surplus increases with lower MTRs.

need for detailed regulatory cost studies for mobile termination and financial transfers between mobile operators. Thus even though MTRs at marginal cost lead to higher welfare than MTRs set at Fully Allocated Cost, after taking into account regulatory and transaction cost the welfare balance may be tipped towards B&K.

55. Finally, as mentioned above, medium-run effects not captured in our modelling framework, such as adjustments in subscriber numbers on fixed and mobile networks, and entry into the mobile market, are likely to lead to further increases in welfare and consumer surplus.

4 Calibration results

56. In this section we discuss our simulation of short-run effects, as derived in the simulations spreadsheet MobileModelUK.xls. The base scenario is given by MTRs set at "LRIC+" estimates from Ofcom, updated by inflation from 2006/07 to 2009/10, of 4.5 ppm for Vodafone, O2, T-Mobile and Orange, and of 4.2 ppm for H3G. The alternative scenarios considered are: "LRMC", reciprocity with the fixed network, and Bill & Keep.

57. In the following we will relate results for call externality parameter "beta" of values 0, 0.5 and 1, while the results for the intermediate values of 0.25 and 0.75 can be consulted in the spreadsheet. Furthermore, we focus our attention on the marginal cost value of 1.0 ppm. The lower value of 0.5 ppm leads to higher increases in welfare, consumer surplus and profits, with the opposite being true for the higher value of 2.0 ppm. Thus we take a conservative stance and report values which lie between extremes.

58. All reported results are stated in £m per calendar year. Increases of the variables under consideration, as compared to the scenario with "LRIC+", are given by positive values, while decreases are given by negative values.

4.1 Aggregate effects

59. Total welfare, i.e. social welfare in the mobile and the fixed market, increases significantly with all three options to lower MTRs below "LRIC+". The extent of the effect clearly depends on the size of the call externality, being highest, to the order of £1bn per year, with a strong call externality.

Table 1: Change in Welfare as compared to "LRIC+" (£m)			
	beta = 0	beta = 0.5	beta = 1
"LRMC"	167	496	964
Recip. Fixed	177	548	1.070
B&K	179	575	1.127

60. This increase in welfare is caused by a reduction in the downward distortion of call quantities due to higher MTRs, both for MTM and FTM calls. All three alternative choices for MTR levels lead to quite similar increases in welfare.

61. It may be surprising that welfare increases both with Reciprocity and Bill & Keep, as compared to "LRMC", even in the case of zero call externalities – considering only mobile telephony, economic theory predicts in this case that welfare is maximized with MTRs at marginal costs. The explanation for this result is that the fixed retention in FTM calls, as described by Ofcom (2007, Annex A19:17), causes a distortion which is alleviated by MTRs below marginal cost.

62. As stated in section 3, the assumption of multi-part tariffs (which are similar to post-paid tariffs) for all mobile consumers implies that lower MTRs lead to higher bundle prices and lower consumer surplus in the mobile market. Without call externalities, this effect dominates and total consumer surplus decreases to some extent. On the other hand, if call externalities are strong enough then total consumer surplus increases by up to almost £600m.

Table 2: Change in Consumer Surplus as compared to "LRIC+" (£m)			
	beta = 0	beta = 0.5	beta = 1
"LRMC"	-75	187	514
Recip. Fixed	-105	191	559
B&K	-129	188	578

63. The sum of profits of the fixed and mobile networks also increases. As indicated above in section 3, under the assumption of multi-part tariffs adopted in this model the predicted increase in profits is higher than under linear tariffs, which implies that our simulated increases in profits are likely in the upper range.

Table 3: Change in Profits as compared to "LRIC+"			(£m)
	beta = 0	beta = 0.5	beta = 1
"LRMC"	242	310	449
Recip. Fixed	282	357	511
B&K	308	387	549

64. Summing up, in the short run total welfare and profits increase with lower MTR, and total consumer surplus also increases if call externalities are strong enough.

4.2 Mobile telephony

65. Now we consider the mobile market only, that is, surplus and profits from making and receiving MTM calls, and from receiving FTM calls. Our simulations indicate that in the short run welfare decreases, with the extent of the decrease again depending on the strength of call externalities.

Table 4: Change in Welfare as compared to "LRIC+"			(£m)
	beta = 0	Beta = 0.5	beta = 1
"LRMC"	-800	-471	-3
Recip. Fixed	-979	-607	-86
B&K	-1.103	-707	-155

66. As discussed in Section 3 and mentioned in the previous section, this decrease is due to the assumption of multi-part tariffs. First, under these tariffs the waterbed effect (transfer of FTM termination profits to mobile consumers) is strong, and lower MTRs will therefore lead to a larger reduction in transfers from the fixed network to mobile consumers. Second, the workings of tariff-mediated network effects imply that lower MTRs reduce the intensity of competition under multi-part tariffs. Under linear tariffs, which are similar to pre-paid tariffs, the waterbed effect is weaker and lower MTRs increase the competitiveness of the mobile market, so that the total effect on consumer surplus is ambiguous.

67. Our simulation results indicate the following short-run changes in consumer surplus under multi-part tariffs. Clearly, the reduction is smaller if call externalities are strong.

Table 5: Change in Consumer Surplus as compared to "LRIC+" (£m)			
	beta = 0	beta = 0.5	beta = 1
"LRMC"	-974	-713	-385
Recip. Fixed	-1.181	-884	-517
B&K	-1.323	-1.006	-615

68. Mobile networks' profits increase, but not enough to compensate for the reduction in consumer surplus due to lower FTM transfers and tariff-mediated network effects.

Table 6: Change in Profits as compared to "LRIC+"			(£m)
	beta = 0	beta = 0.5	beta = 1
"LRMC"	175	242	382
Recip. Fixed	202	277	431
B&K	219	299	460

69. Summing up, in our short-run simulations welfare and consumer surplus in the mobile market decrease, while profits increase, with MTRs lowered below "LRIC+". In the medium to long run, though, lower MTRs are likely to change the very structure of the market, leading to more entry and more competitive small networks, which should at least in part reverse these short-run effects.

4.3 Fixed telephony

70. Now we consider the effects of changing MTRs on the fixed network and its clients. The model includes profits and surplus from FTM calls, and consumer surplus from receiving MTF calls (fixed termination rates are set at cost, so that there are no termination profits).

71. The calibrated 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 MTF price does not change with the MTR. While in the following tables all three columns contain the same values, for clarity we do not change the table format.

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

Table 7: Change in Welfare as compared to "LRIC+"			(£m)
	beta = 0	beta = 0.5	beta = 1
"LRMC"	967	967	967
Recip. Fixed	1.155	1.155	1.155
B&K	1.282	1.282	1.282

73. Almost all of the increase in welfare on the fixed network is due to the increase in consumer surplus due to lower FTM calls prices and higher call quantities. Note that this increase on consumer surplus on the fixed network

is of the same order of magnitude as the decrease in consumer surplus on mobile networks, which indicates that most of the effect stems from the reduction in transfers to mobile networks.

Table 8: Change in Consumer Surplus as compared to "LRIC+" (£m)			
	beta = 0	beta = 0.5	beta = 1
"LRMC"	900	900	900
Recip. Fixed	1.075	1.075	1.075
B&K	1.194	1.194	1.194

74. Profits of the fixed network only increase slightly in our simulations, at least as compared to consumer surplus in the same market. This increase in profits is strictly due to the fixed retention (the fixed network's margin above MTR) being applied to a larger number of call minutes.

Table 9: Change in Profits as compared to "LRIC+" (£m)			
	beta = 0	beta = 0.5	beta = 1
"LRMC"	68	68	68
Recip. Fixed	80	80	80
B&K	89	89	89

75. Summing up, it is clear that in the short run on the fixed network the principal benefit of lower MTRs goes to consumers, through lower FTM prices, but profits also increase.

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References

Analysys Mason (2008) *Case studies of mobile termination regimes in Canada, Hong Kong, Singapore and the USA, Report for Ofcom*, 26 November.

Andersson, K. and B. Hansen (2009) "Network competition: Empirical evidence on mobile termination rates and profitability", mimeo, 3 March.

Armstrong, M. and J. Wright (2007) "Mobile Call Termination in the UK," MPRA Paper No. 2344, 21 March.

Berger, U. (2004) "Access Charges in the Presence of Call Externalities," *B.E. Journal of Economic Analysis & Policy*, 3(1).

Berger, U. (2005) "Bill-and-Keep vs. Cost-Based Access Pricing Revisited," *Economics Letters*, 86(1), 107-112.

Cabral, L. (2009) "Dynamic Price Competition with Network Effects," mimeo, New York University, April;

Cabral, L. (2008) "Modeling Competition and Regulation in Wireless Telecommunications: A Dynamic Perspective," mimeo, New York University, February.

Calzada, J. and T. Valletti (2008) "Network Competition and Entry Deterrence," *Economic Journal*, 118, 1223-1244.

Cambini, C. and T. Valletti (2007) "Information Exchange and Competition in Communications Networks," forthcoming in *Journal of Industrial Economics*.

De Bijl, P. and M. Peitz (2002) *Regulation and Entry Into Telecommunications Markets*, Cambridge University Press, Cambridge.

DeGraba, P. (2003) "Efficient Intercarrier Compensation for Competing Networks when Customers Share the Value of a Call," *Journal of Economics and Management Strategy*, 12, 207-230.

European Commission (2009a) *Commission Recommendation on the Regulatory Treatment of Fixed and Mobile Termination Rates in the EU*, 7 May, Brussels.

European Commission (2009b) *Explanatory Note,* Commission Staff Working Document accompanying the Commission Recommendation on the Regulatory Treatment of Fixed and Mobile Termination Rates in the EU, Brussels.

European Commission (2009c) *Implications for Industry, Competition and Consumers,* Commission Staff Working Document accompanying the Commission Recommendation on the Regulatory Treatment of Fixed and Mobile Termination Rates in the EU, Brussels.

Genakos and Valletti (2009) "Testing the 'Waterbed' Effect in Mobile Telephony", mimeo.

Harbord, D. and M. Pagnozzi (2008) "On-Net/Off-Net Price Discrimination and 'Bill and - Keep' vs. 'Cost-Based' Regulation of Mobile Termination Rates," forthcoming in *Review of Network Economics*.

Hermalin, B. and M. Katz (2006) "Customer or Complementor? Intercarrier Compensation with Two-Sided Benefits," mimeo, Haas School of Business, University of California, Berkeley.

Hoernig, S. (2007) "On-Net and Off-Net Pricing on Asymmetric Telecommunications Networks," *Information Economics & Policy*, 19(2), 171-188.

Hoernig, S. (2008) "Tariff-Mediated Network Externalities: Is Regulatory Intervention any Good?" CEPR Discussion Paper No. 6866.

Hoernig, S. (2009) "Competition between Multiple Asymmetric Networks: A Toolkit and Applications" mimeo, FEUNL.

Jeon D., J.-J. Laffont and J. Tirole (2004) "On the Receiver Pays Principle," *RAND Journal of Economics*, 35, 85 -110.

Ofcom (2007) "Mobile call termination" Statement, 27 March.

Ofcom (2009) *Wholesale Mobile Voice Call Termination: Preliminary Consultation on Future Regulation*, 20 May, London.

Peitz, M. (2005a) "Asymmetric access price regulation in telecommunications markets," *European Economic Review*, 49, 341-358.

Quigley, N. and I. Vogelsang (2003) Interconnection Pricing: Bill and Keep Compared to TSLRIC, Charles River Associates (Asia Pacific) Ltd.

Taylor, L.D. (2004) "Customer Demand Analysis," in Cave, M., Majumdar, S. and Vogelsang, I. (eds.), *Handbook of Telecommunications Economics* (North-Holland, Amsterdam).

Annex A: Model Calibration

Our model has been calibrated with data mostly from Ofcom's "Mobile Call Termination" Statement of 27 March 2007 (in the following referred to as "Statement"). The calculations have been performed in Excel (see file MobileModelUK.xls).

Utility and Demand Parameters on mobile networks: Linear demand functions have been calibrated from Statement A19:13 (67.051m subscribers, 96,472m call minutes per year, price per minute 11.84 pence) and A19:15 (demand elasticity 0.3). We have assumed a given number of calls per subscriber per million potential recipients, which does not affect our results.

Utility and Demand Parameters on the fixed network: Linear demand functions have been calibrated from Ofcom, Telecommunications market data update Q3 2007, February 2008, Table 2 (33,682m subscribers), Statement A19:13 (24,705m call minutes per year, price per minute 10.96 pence) and A19:15 (demand elasticity 0.3). We have assumed a given number of calls per subscriber per million potential recipients, which does not affect our results.

Market shares: These refer to subscriber numbers at the end of Q4 2008 and have been obtained from H3G (rounded to the full digit). Furthermore, we have chosen a value in the stable range for the differentiation parameter of the underlying imperfect competition model. The choice of this parameter has no influence on welfare results, and little influence on the distribution of total welfare over profits and consumer surplus.

Costs on mobile networks: Fixed cost per mobile subscription have been obtained from Statement A19:18 (£95.38 per year), while we have assumed three different levels for the (long-run) marginal costs of originating and termination calls: 0.5 ppm, 1 ppm, 2ppm.

Costs and FTM prices on the fixed network: We assume the marginal costs of origination and termination on the fixed network are identical and equal to 0.4ppm, which is the estimate we have received from H3G. Furthermore, we maintain Ofcom's assumption in Statement A19:17 that the fixed network sets the FTM price by charging a fixed retention of 3.51ppm over the average mobile termination rate.

Annex B: Technical description of the UK mobile market model
(Steffen Hoernig, Universidade Nova de Lisboa, Portugal)

1. Networks:
There are five mobile networks with subscriber market shares $\alpha_i > 0$, $\sum_{i=1}^{5} \alpha_i = 1$, and one fixed network. All mobile networks are interconnected with each other and the fixed network.

Mobile network i incurs a yearly fixed cost per customer of f_i, and has on-net cost $c_{ii} = c_{oi} + c_{ti}$ per call minute, where the indices o and t stand for origination and termination, respectively. The mobile termination rate (MTR) on network i is a_i, so that the perceived costs of off-net calls from network i to network $j \neq i$ are $c_{ij} = c_{oi} + a_j$.

The termination rate on the fixed network (FTR) is $a_f = c_{tf}$, the cost of call termination on the fixed network. Thus the perceived cost of a call from mobile network i to the fixed network is $c_{if} = c_{io} + a_f$. Here we only consider calls between the fixed and mobile networks and neglect other services on the fixed network, including on-net calls.

2. Tariffs: Mobile network i charges a two-part tariff, with a (yearly)[1] subscription fee F_i, plus a per-minute call price 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 call price to the fixed network p_{if} is set separately.

The fixed network charges a per-minute price p_{fm} for calls to mobile networks, which we assume to be equal to the (weighted) average MTR $\bar{a} = \sum_{i=1}^{5} \alpha_i a_i$ plus a fixed retention r_f to cover its cost of origination: $p_{fm} = r_f + \bar{a}$.

3. Consumers: There are a total of M subscribers in the mobile market, and N subscribers of the fixed network. We assume a balanced calling pattern, i.e. on mobile networks calls are made to all potential receivers with the same probability d per one million users (and correspondingly d_f for calls originated on the fixed network).[2] The utility derived from making, or receiving, a call of length q is $u(q)$, or $\beta u(q)$, respectively, where $\beta \geq 0$ indicates the strength of the call externality. Given a per-minute price p, consumers demand calls of length $q(p)$, with the resulting surplus of $v(p) = u(q(p)) - pq(p)$. In the following we will use the shorthands $q_{ij} = q(p_{ij})$, $u_{ij} = u(q_{ij})$, $v_{ij} = v(p_{ij})$ etc., for all $i, j \in \{1, ..., 5, f\}$.

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

[2] Given the linearity of the calibrated demand function $q(.)$, the chosen values for d and d_f do not matter. Their only function is to calibrate realistic call quantities per consumer.

A client of network i then obtains the following surplus from making and receiving calls to and from mobile networks and the fixed network:

$$\begin{aligned} w_i &= dM\sum_{j=1}^{5}\alpha_j\left(v_{ij}+\beta u_{ij}\right)+dN\left(v_{if}+\beta\frac{d_f}{d}u_{fi}\right)-F_i \\ &= dM\sum_{j=1}^{5}\alpha_j h_{ij}+dNh_{if}-F_i \end{aligned}$$

where $h_{ij}=(v_{ij}+\beta u_{ij})$ and $h_{if}=\left(v_{if}+\beta\frac{d_f}{d}u_{fi}\right)$. In matrix notation, this can be written as[3]

$$w = dMh\alpha + dNh_f - F, \tag{1}$$

where we have introduced the matrix $h=(h_{ij})_{ij}$ and the vectors $w=(w_i)_i$, $\alpha=(\alpha_i)_i$, $h_f=(h_{if})_i$ and $F=(F_i)_i$. Aggregate consumer surplus on mobile networks is then given by

$$S = M\alpha' w \tag{2}$$

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

$$S^f = Nd^f M\sum_{i=1}^{5}\alpha_i\left(v_{fi}+\beta\frac{d}{d^f}u_{if}\right)=N\alpha' d^f M g_f,$$

where $g_{fi}=v_{fi}+\beta\frac{d}{d^f}u_{if}$ and $g_f=(g_{fi})_i$.

4. Market shares: We assume that consumers consider mobile networks as differentiated in Hotelling fashion, with 5 asymmetric firms in the market. The resulting expression of market shares is

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

where α_{0i} captures ex-ante asymmetries in brand loyalty and customer valuation of operators, and $\sigma>0$ measures the degree of differentiation between operators' offers. In matrix terms, this becomes

$$\alpha = \alpha_0 + \sigma Bw, \tag{3}$$

where $\alpha_0=(\alpha_{0i})_i$ and $B=(B_{ij})_{ij}$ with $B_{ii}=4$ and $B_{ij}=-1$ if $i\neq j$.

[3]For these and other mathematical details, consult Hoernig (2009).

Combining (1) and (3), and solving for α, we obtain the equilibrium market shares for given tariffs,

$$\alpha = G\alpha_0 + \sigma H \left(dNh_f - F \right) \tag{4}$$

where $G = \left(I - \sigma dMBh \right)^{-1}$ and $H = \left(H_{ij} \right)_{ij} = \left(I - \sigma dMBh \right)^{-1} B$.

The market outcome is stable in customer expectations if $\sigma \in (0, 1/\kappa)$, where κ is largest eigenvalue of $dMBh$, if this eigenvalue is positive.

5. Profits and Welfare

Network i's profits are given by

$$\pi_i = M\alpha_i \left(dM \sum_{j=1}^{5} \alpha_j R_{ij} + dNQ_i + F_i - f_i \right), \tag{5}$$

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

$$\Pi = M\alpha' \left(dMR\alpha + dNQ + F - f \right), \tag{6}$$

where $R = \left(R_{ij} \right)_{ij}$, $Q = \left(Q_i \right)_i$ and $f = \left(f_i \right)_i$.

The profits of the fixed network from FTM calls are

$$\pi^f = Nd^f M \sum_{i=1}^{5} \alpha_i r_f q_f = Nd^f M r_f q_f. \tag{7}$$

Total welfare is then

$$W = S + S^f + \Pi + \pi^f. \tag{8}$$

6. Equilibrium outcomes

It can be shown through standard techniques that equilibrium call prices on mobile networks will take on the following form:

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

Equally, it can be shown that equilibrium fixed fees are given by

$$F = f - dNQ + dM\left(\hat{R} - R\right)\alpha,$$

where $\hat{R} = \left(\hat{R}_{ij}\right)_{ij}$ with $\hat{R}_{ij} = 0$ if $i \neq j$ and

$$\hat{R}_{ii} = \left(\frac{1}{\sigma dM H_{ii}} - \sum_{j=1}^{5} \frac{H_{ji}}{H_{ii}} R_{ij}\right).$$

Network i's equilibrium profit is $\pi_i = \alpha_i^2 dM^2 \hat{R}_{ii}$.

References:

Hoernig, Steffen (2009), "Competition between multiple asymmetric networks: A toolkit and applications", mimeo, Universidade Nova de Lisboa.