National Roaming Pricing in Mobile Networks

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Abstract

This paper develops a practical model of optimal and competitive neutral national roaming access prices. This method takes account of the geographical cost structure of the networks, and thus allows for the "cream-skimming" effect whereby a new entrant will concentrate its own network build in low cost (higher traffic density) urban areas, especially when its uses a technology that has a cost advantage in these areas.

Both networks will invest in more geographic coverage when the national roaming access price is set higher – the incumbent will do so because of the extra revenue it will get from roaming charges, and the new entrant will do so in order to avoid paying roaming charges to the incumbent.

The paper provides an illustration of how the method could be applied to a situation where the host incumbent is restricted to GSM 900 against a new entrant deploying WCDMA 2.1 GHz. Under realistic assumptions we have calculated that a competitively neutral national roaming access price will be about 38% above the average cost on the host incumbent's network, although this result will depend on the specific distributions of traffic against geography in the country concerned. An access price set at this level will ensure competitive neutrality between networks, and provide efficient investment signal for the new entrant network.

1. Introduction

National roaming enables a new mobile entrant to compete against existing incumbent mobile networks in the absence of full national coverage by its own infrastructure. A common scenario is where the new entrant provides its own network infrastructure only in urban areas, and relies on roaming onto an incumbent's network in the rest of the country. New 3G network operators invariably require national roaming to provide full national coverage, because of the high cost of building a WCDMA network at 2.1 GHz in rural areas.

What wholesale price should the new entrant pay in any commercially negotiated national roaming deal, or what rate should be set under regulatory oversight?[2] There are a number of possible answers to this question:

- A national roaming access price equal to the incremental cost of traffic of the new entrant's traffic on the host incumbent's network. An efficient economic price needs to cover the

[1] The views expressed in this paper are those of the author, and should not necessarily be attributed to Vodafone.

[2] National roaming access prices are normally commercially negotiated, since the new entrant will have a competitive choice of host networks.

marginal costs (including the full economic costs of additional capacity) imposed on the host network. A price below this will mean that the new entrant can provide services at a price to the end user below the true economic cost of the resources it uses. However, a national roaming rate set on this basis would be very damaging for competition. The entire fixed costs of building and operating the network in the geographic regions where the new entrant used national roaming would fall on the host incumbent. If we reasonably presume that the new entrant would only require national roaming in rural areas, where coverage costs are high compared to capacity costs, these fixed costs would be large, and the new entrant would be at a considerable cost advantage over the incumbent;

- A national roaming access price equal to the average cost of traffic on the host incumbent's network. However, where the new entrant focuses its own network build on urban areas, the new entrant would remain at a cost advantage, since it could combine the low costs of self-building urban areas with a national roaming access price based on national average costs in rural areas. Effectively the host incumbent would be subsidising the new entrant's traffic in rural areas. The incumbent network could fall victim to "cream skimming" by the new entrant, with the result that competition will be distorted and ultimately the dynamic efficiency of the competitive market will be damaged;

- A national roaming access price that leaves the incumbent's profits unaltered. This is the so-called Efficient Component Pricing Rule (ECPR). The rationale for this rule is that the new entrant should only be successful in the market to the extent that it is equally or more efficient as the incumbent. A less efficient new entrant (supported by a low national roaming access price) would be detrimental to the overall economic efficiency of the industry and, ultimately, would be detrimental to consumer interests. The ECPR leads to the conclusion that the national roaming access price should reflect the incremental cost of the roaming traffic on the host incumbent's network, plus the lost profit margin from the incumbent not supplying this traffic itself at a retail level. This leads to a national roaming rate set equal to the incumbent's retail price less avoided retail costs ("retail-minus"). The principal objection to the ECPR is that it takes the existing retail prices as already efficient or competitive, and denies the possibility that there is scope for an efficient new entrant (albeit one that required national roaming) to provide additional competitive pressure to lower this prices. Thus, national roaming prices set on this basis would be inconsistent with the objective of enhancing competition through a new entrant;

- A national roaming access price that allows an efficient new entrant to achieve the same level of profitability as the incumbent – the competitive equality criterion. We concentrate on this criterion since it is the only one that is consistent with the objective of enhancing efficient competition through new entry.

Achieving the correct rate for the national roaming access price becomes particularly important if the new entrant operates a WCDMA 2.1 GHz network, and has no technological flexibility (perhaps because of its license).[3] Other things being equal, spectral efficiencies should provide 3G operators with greater traffic capacity, and so in areas where the network is dimensioned for capacity (rather than coverage), as will often be the case in urban areas, unit costs can be expected to be lower than for a GSM 900 MHz network carrying the same amount of traffic and with the same absolute amount of allocated spectrum. However, the situation reverses in rural

[3] Throughout this paper we assume that the new entrant has no flexibility in the technology (or at least the spectrum) that it has been allocated. Clearly if it has flexibility it should be able to achieve a cost base at least as low as the incumbent (for the same volume of traffic). The exposure of the incumbent to cream skimming under a national roaming agreement would then be even higher.

areas, where the network needs to be dimensioned for coverage rather than capacity. Here the cost advantage will lie with GSM 900, rather than WCDMA at 2.1 GHz.[4]

Therefore, the national roaming access price that seeks to preserve a competitive neutral market (to maximise the dynamic efficiency between competitors) will need to allow for:

- The higher costs that the incumbent faces in rural areas, where the demand for national roaming will be greatest;
- The cost disadvantage it may face in urban areas, if it is restricted to GSM 900 technology.

It follows, therefore, that in determining a national roaming access price (by either commercial negotiation or regulatory over-sight) the geographical cost structure of both the incumbent and the new entrant network will be relevant (the latter only in the case where the incumbent doesn't have access to the same technology as the new entrant). The time profile of national roaming prices is also relevant. As the new entrant network expands its network coverage, a greater proportion of the roaming traffic is in more remote areas, with progressively higher unit cost. Setting a time profile for roaming according to an ex-ante anticipated efficient network build will provide the correct incentives for the new entrant to complete a geographical network build consistent with efficient investment.

Section 2 of this paper develops a formal model which is used to specify a competitive neutral national roaming access price. Section 3 develops this model further to investigate the impact of the access price of national roaming on incentives for network investment, and how the access price should be set to give the correct signal for efficient investment by the new entrant. Section 4 presents conclusions.

2. Competitive neutral national roaming rate

In this section we introduce the basic model in which we determine a competitive neutral national roaming access price, and illustrate this model through a calibration.

Model

Assume that the costs of building a mobile network, i, can be expressed as the sum of coverage and capacity costs:

$$C_i = v_i V_i + m_i(q + r) \qquad (1)$$

Where:

V_i is geographical coverage (in km^2) of network i;

v_i is the coverage cost (per km^2), dependent on the network technology (e.g. GSM 900 or WCDMA 2.1GHz), of network i;

q is the volume of airtime minutes originated or terminated by subscribers to network i;

4 Although the situation would be different if spectrum re-farming were permitted.

r is the volume of airtime minutes originated or terminated by subscribers to networks roaming on network i;

m_i is the marginal cost, dependent on the network technology (e.g. GSM 900 or WCDMA 2.1GHz), of a minute of airtime on network i.

We will assume that there are two networks: an incumbent operating a GSM 900 network which we take to be network i, and a new entrant operating a WCDMA 2.1GHz network which we take to be network j. The characteristics of the respective technologies are such that:

$$v_i < v_j \quad (2a)$$

$$m_i > m_j \quad (2b)$$

It will evidently be the case that network i will have the greater own-network geographical coverage of the two networks. We suppose, however, that there will be a national roaming agreement that will provide network j with the same geographical coverage. We suppose, therefore, that there will be no quality or consumer preference differences between the two networks,[5] and that in competitive equilibrium both networks offer the same market price, p, and have potential to win the same volume of own subscriber traffic, q.[6] The main question of this paper is to determine the national roaming access price, a, paid by network j to network i that ensures that this competitive equilibrium will be achieved.

Reflecting the national roaming relationship between the two networks, we can write the profit functions as:

$$\pi_i = pq - v_i V_i - m_i(q + r) + ar \quad (3a)$$

$$\pi_j = pq - v_j V_j - m_j(q - r) - ar \quad (3b)$$

We now need to specify the relationship between V_i and q:

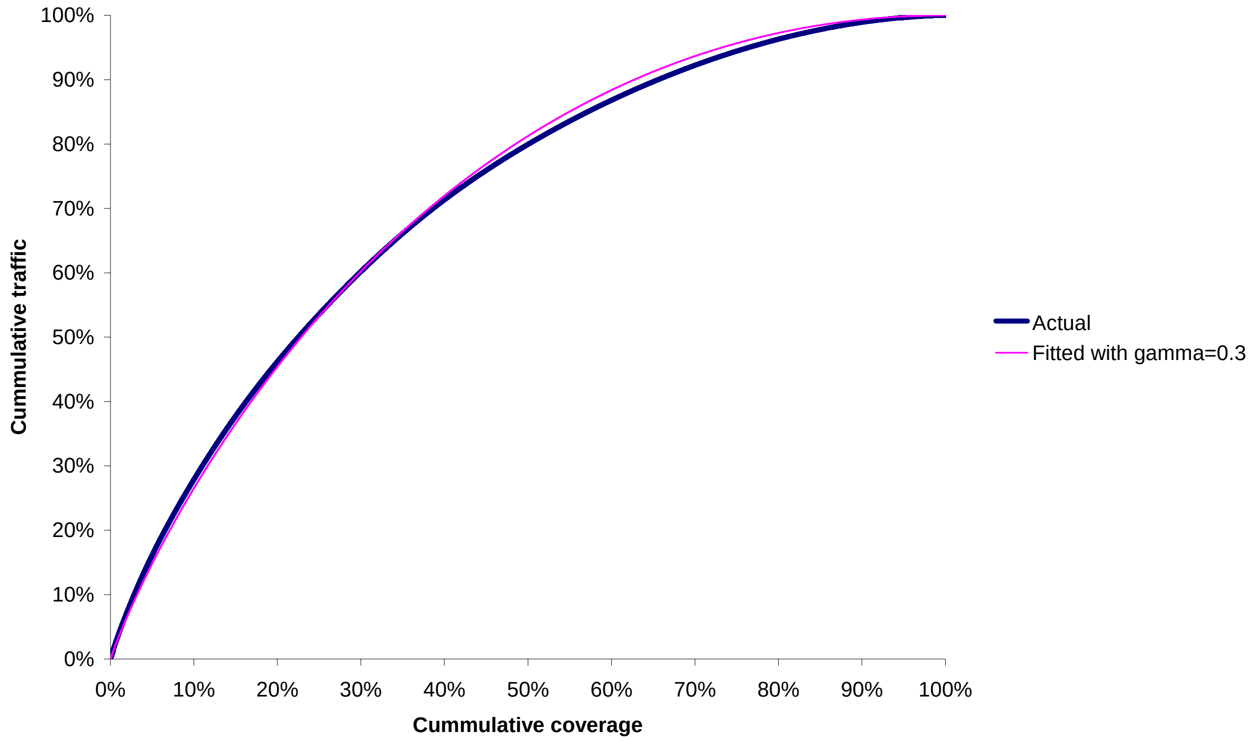
$$q = Q\varphi(V_i) \quad (4)$$

where Q is the traffic volume once full national coverage has been achieved, thus $0 \le \varphi(V_i) \le 1$ with $\varphi(0) = 0$. We can further restrict $\varphi'(V_i) \ge 0$ and $\varphi''(V_i) \le 0$, since we would expect the network to spread out from the most traffic rich areas. Figure 1 shows this relationship for one of Vodafone's developed country networks.

[5] We do not model any advantage that the WCDMA network may have in offering 3G services.

[6] We do not deny that in the short term the new entrant will have a lower traffic share, but it is the long term competitive equilibrium for efficiently operated networks that needs to be considered for the competitive neutral national roaming access price.

Figure 1: $\varphi(V)$ in developed country



We can now determine the volume of airtime on network j as:

$$q - r = Q\varphi(V_j) \qquad (5a)$$

And the volume of national roaming traffic as:

$$r = Q[\varphi(V_i) - \varphi(V_j)] \qquad (5b)$$

Substituting into the profit functions of equations (3) gives:

$$\pi_i = [(p - 2m_i + a)\varphi(V_i) - (a - m_i)\varphi(V_j)]Q - v_i V_i \qquad (6a)$$

$$\pi_j = [(p - a)\varphi(V_i) + (a - m_j)\varphi(V_j)]Q - v_j V_j \qquad (6b)$$

We now consider three variants of a model:

Variant 0: Coverage of both networks is exogenous. The host incumbent provides full national coverage and the new entrant provides only limited coverage.

Variant 1: Coverage of both networks is endogenous, i.e. optimised to maximise profits given respective cost functions. We would expect the incumbent to have a near national coverage network, and the new entrant a limited coverage network, depending on costs and the national roaming access price.

Variant 2: Coverage of the incumbent network is exogenous (full national coverage), and coverage of the new entrant network is endogenous, i.e. optimised to maximise profits given its cost functions and the national roaming access price price.

Variant 0: Exogenous coverage of both networks

This variant proceeds on the basis that network i has full national coverage of the land mass (so that $\varphi(V_i) = \varphi(A) = 1$) and network j has some lesser coverage, but nevertheless taken as being fixed.

In this case it is simple to calculate the competitive neutral national roaming access price by setting $\pi_i = \pi_j$ and solving:

$$a = m_i + \frac{v_i V_i - v_j V_j + (m_i - m_j)\varphi(V_j)Q}{2[1-\varphi(V_j)]Q} \qquad (7)$$

This result simply says that the national roaming access price should be set equal to the marginal cost of traffic on the incumbent host network plus a term equal to half of:

- the cost difference between the two networks in respect to the overall coverage costs (taking account of the larger coverage of the host incumbent network);
- the capacity costs of the two networks in respect to that proportion of the traffic carried on the new entrant's own network (which may be smaller for the new entrant if it alone has access to WCDMA 2.1 GHz technology);
- with both the above spread over the volume of roaming traffic.

This makes intuitive sense. The host incumbent network is compensated for the incremental costs caused by the new entrant's roaming traffic, and in addition there is an adjustment for the intrinsic cost advantage or disadvantages between the networks over the geographical area in which the networks overlap, spread over the volume of roaming traffic. Thus the competitive neutral national roaming access prices is:

- increased if the incumbent host network has larger marginal costs of traffic;
- increased if it provides greater network coverage (which is made available to the new entrant);
- increased if the new entrant has access to a technology with lower capacity costs within the coverage of its own network;
- increased by the fact that the new entrant will only require roaming over a portion of the host incumbent's network where traffic is lower relative to coverage costs.

In the extreme case, where the new entrant has no own-network, the competitively neutral national roaming access price is simply the marginal cost on the host incumbent's network, plus a half share if its coverage costs spread over all the new entrant's (roaming) traffic.

Calibration

We now illustrate how this calculation may look in practise. We first need to quantify the relationship between traffic and coverage. This can readily be done by the incumbent network, as shown by the example in Figure 1. We parameterise this by a particular functional form:

$$\varphi(V) = \frac{\left(V/A\right)\left[1+\gamma-\left(V/A\right)^{\gamma}\right]}{\gamma} \qquad (8)$$

where A is the total land mass of the country in km^2. This parameterisation gives a very close fit to the actual data from Figure 1 when $\gamma = 0.3$. This is typical of many developed networks, whereby 50% land mass coverage allows 81% of the traffic to be captured, and 90% land mass coverage allows over 99% of traffic to be captured.

We next need cost functions for the two networks. Table 1 shows an analysis of the costs of an omni-sector base station in the UK, which can be taken as being indicative of the non-traffic costs of coverage.[7]

Table 1:

Illustrative coverage costs

	Investment	Asset life (years)	WACC	Annuitised investment cost	Opex	Total cost
Site acquisition, preparation and civil works	£80,526	20	15%	£12,865	£9,018	£21,883
Equipment (omni-sector)	£61,369	10	15%	£12,228	£6,692	£18,920
Total	£141,895			£25,093	£15,710	£40,803

	Cell coverage	Cost/km^2
GSM 900	51km^2	£800
WCDMA 2.1 GHz	13km^2	£3,200

Source: OFCOM model, and Vodafone analysis

We also require estimates of the marginal cost of traffic. We assume a cost of 4ppm for a GSM 900 network (noting that the OFCOM model estimates 4.9ppm for a 2G network, including

[7] Although multi-sector base stations (usually 3-sector) are more common, an omni-sector base station gives a better indication of the underlying coverage costs, excluding any costs of traffic capacity.

coverage costs). Costs will be lower for a WCDMA 2.1GHz network due to spectral efficiencies. We can estimate the WCDMA 2.1GHz costs to be 2.8ppm.[8]

Chart 2 shows the resulting competitive neutral national roaming access price. At low levels of new entrant coverage this reflects the geographically averaged costs on the host incumbent network (at marginal cost of 4.25ppm). As the new entrant expands its own network into initially high traffic density urban areas, and restricts its national roaming requirements to lower traffic density rural areas, the national roaming rate rises accordingly. It continues to rise until coverage of about 75% is achieved. Beyond this point WCDMA 2.1 GHz coverage becomes uncompetitive and, if this level of coverage were to be provided the new entrant would require a subsidy which, in the model, is reflected in a reduced national roaming rate for the remaining area it does not cover. Since the amount of roaming traffic becomes very small at these high levels of coverage, the WCDMA 2.1 GHz subsidy becomes very large when expressed in terms of a national roaming access price.[9]

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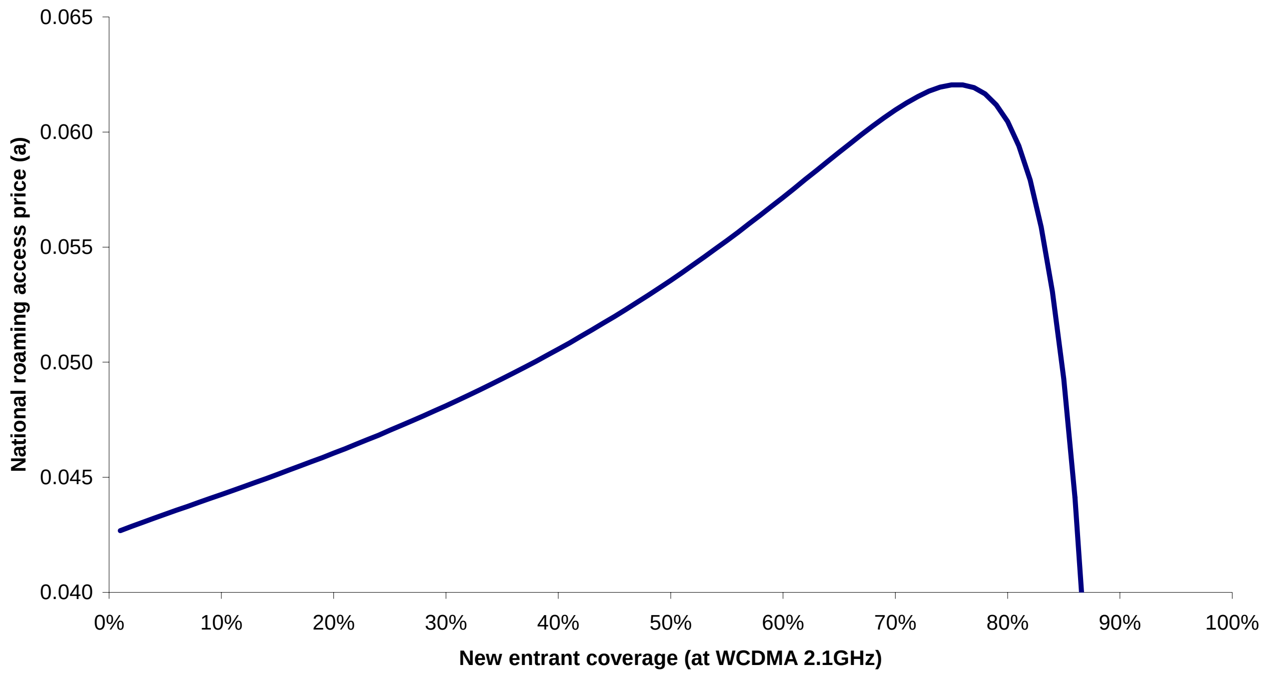
8 WCDMA provides more airtime capacity that GSM on each cell site. WCDMA transceivers use 5MHz of spectrum, but allow around 60 voice channels on each transceiver, compared to only 8 channels on 200 kHz of spectrum for a GSM network (assuming full rate voice codec). More importantly, WCDMA allows significantly more efficient use of the spectrum, effectively providing re-use of spectrum in neighbouring sectors, compared to an average spectrum re-use factor of around 12 under GSM networks. Therefore, in rough terms, WCDMA allows for approximately 12 channels/Mhz, compared to only 3.3 for GSM. Therefore, the incremental cost of capacity at a WCDMA cell site is lower by a factor of about 3.6. In practise the difference is not so pronounced if half rate voice codec is used within the GSM network in order to better utilise capacity. In some situations half rate voice codec can be used for up to about 40% of call volumes without seriously compromising voice quality, thus increasing capacity within the GSM network by a factor of 1.4. In conclusion, therefore, the capacity difference between a GSM and WCDMA network is reduced from 3.6 to 2.6, which can be considered as translating into a marginal cost reduction of about 62% at the air interface. However, the air interface related costs account for only 50% of the total marginal costs (others being backhaul and core network), and so the actual WCDMA cost saving is more likely to equal about 31%.

9 This is not a realistic scheme for subsidising WCDMA 2.1 GHz coverage.

Chart 2:

Competitive neutral national roaming access price



The dependency of national roaming access prices on the geographic area required by the new entrant is explicitly recognised in, for example, the proposals of Vodafone New Zealand.[10] A base national roaming headline price is established. This will reflect the average costs of traffic across the whole network. Costs are then calculated for the radio access network in the entire national network, and also a subset of the network over which the new entrant will require roaming (i.e. excluding "Exclusion Zones" where the new entrant has its own network). This allows a relative cost differential to be calculated, that is then used to adjust the headline roaming price.

3. The national roaming access prices and incentives to invest

The methodology of Section 2 points to the possibility of applying a national roaming access price conditional of the network coverage achieved by the new entrant. As the new entrant expands network coverage in low cost urban areas, and restricts its roaming requirements to high cost rural areas, the roaming rate will rise to preserve the competitive neutrality of the market, effectively neutralising any "cream skimming" by the new entrant.

A drawback with this approach is that a national roaming access price that rises with the new entrant's network coverage may disincentivise the new entrant to invest. The way to avoid this disincentive is to set the access price, not conditional on actual network coverage, but on the new entrant's "optimal" coverage, or a time path leading to an optimal network coverage. In the event that the new entrant fails to achieve this level of network build, it will still be required to pay the roaming rate that would apply if it did. This will incentivise the new entrant to achieve the optimal

[10] http://www.comcom.govt.nz/IndustryRegulation/Telecommunications/Investigations/mobilemarket.aspx

level of network build in order to achieve a competitive neutral national roaming access price, and will not reward an inefficient new entrant (that under-builds) with a lower access price.

We develop two Variants of the model. In the first we endogenise the network coverage of both the host incumbent and the new entrant. In the second we assume that the host incumbent has full national coverage and endogenise only the network coverage of the new entrant.

Variant 1: Endogenous coverage in both networks

The first variation will proceed on the basis that neither network has complete national coverage (although network i will have greater coverage than network j). We need to consider the optimal (or profit maximising) build of both networks, which will endogenously depend on p and a.

Both networks will seek a level of network coverage (V_i and V_j) that will maximise profits. First order conditions with respect to V_i and V_j, valid whenever $a > 2m_i - p$ and $a > m_j$, give[11]:

$$\varphi'(V_i) = \frac{v_i}{(p + a - 2m_i)Q} \tag{9a}$$

$$\varphi'(V_j) = \frac{v_j}{(a - m_j)Q} \tag{9b}$$

Taking the specific functional form in equation (8) we have:

$$\varphi'(V) = \frac{\left(1 + \frac{1}{\gamma}\right)\left[1 - \left(\frac{V}{A}\right)^{\gamma}\right]}{A} \tag{10}$$

And so:

$$V_i = A\left[1 - \frac{\gamma}{1+\gamma}\frac{v_i}{(p + a - 2m_i)}\frac{A}{Q}\right]^{\frac{1}{\gamma}} \tag{11a}$$

$$V_j = A\left[1 - \frac{\gamma}{1+\gamma}\frac{v_j}{(a - m_j)}\frac{A}{Q}\right]^{\frac{1}{\gamma}} \tag{11b}$$

11 Second order conditions are easily checked:

$$\frac{\partial^2 \pi_i}{\partial V_i^2} = (p - 2m_i + a)\varphi''(V_i)Q < 0 \qquad \text{if } a > 2m_i - p$$

$$\frac{\partial^2 \pi_j}{\partial V_j^2} = (a - m_j)\varphi''(V_j)Q < 0 \qquad \text{if } a > m_j$$

Both these conditions will be fulfilled if a and p at least exceed marginal cost on both networks (which we would expect).

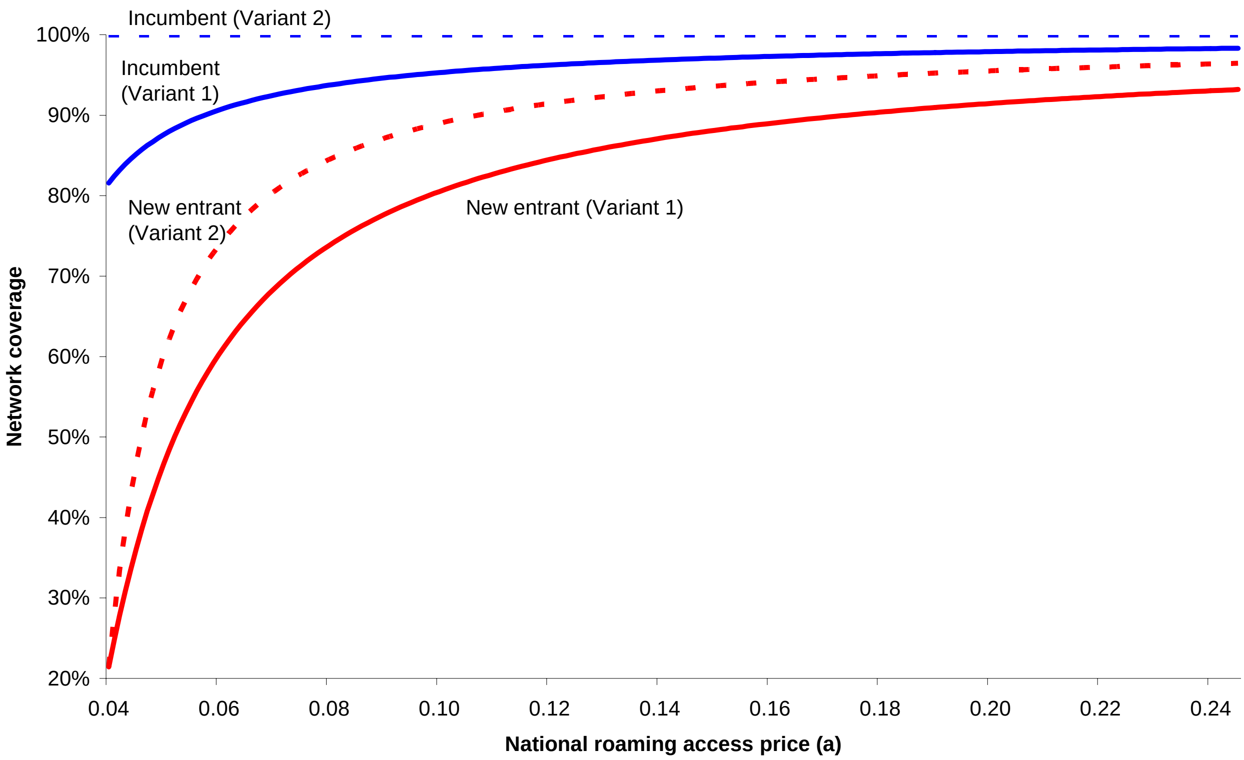
The interesting conclusion of equations (11) is that both networks will invest in more geographic coverage when the national roaming access price is set higher – the incumbent will do so because of the extra revenue it will get from roaming charges, and the new entrant will do so in order to avoid paying roaming charges to the incumbent.

It is also interesting that whilst the incumbent decides the extent of investment in geographical coverage on the basis of retail prices (since a higher retail price makes investment in marginal areas more profitable), the new entrant is not directly concerned with the price. This is because the new entrant's geographic coverage at a retail level is determined by that of the incumbent (through national roaming), not its own investment. Rather, the new entrant's network investment objective will be solely cost minimisation – a "make-or-buy" decision.

Chart 3 shows the optimal network coverage of both networks as a function of the national roaming access price.

Chart 3:

Network coverage and national roaming rate



We are primarily interested in the level of a that will ensure the competitive neutrality between the two network, i.e. $\pi_i = \pi_j$, assuming that both networks invest optimally (efficiently) in geographic network roll-out. Solving this problem with the assumptions stated in Table 1 gives $a = 5.3$ ppm with coverage of $V_i = 89\%$ and $V_j = 52\%$ by the host incumbent and new entrant networks respectively.

Variant 2: Complete geographical coverage

We now look at the variant where the incumbent has built a complete national coverage network, i.e. $\varphi(A)=1$. This allows us to relax our assumption of a fixed value of p (which in the previous case determined the incumbent's geographic network roll-out). We can now assume that, in a mature market, super-normal profit will be eliminated by competition, and so that p will be set such that $\pi_i = 0$. In this way we recognise that, rather than being fixed, p will depend on a. In particular, a higher value of a will directly generate more national roaming revenue for the incumbent, but also cause the new entrant to extend its own geographic network coverage, thus off-setting the incumbent's roaming revenues. Both these factors will affect p.

The incumbent's profit equation from equation (6a) becomes:

$$0 = \left[p - 2m_i + a - (a - m_i)\varphi(V_j)\right]Q - v_i A \qquad (12)$$

So that we solve:

$$p = \frac{v_i A}{Q} + 2m_i - a + (a - m_i)\varphi(V_j) \qquad (13)$$

Substituting this into equation (12), the new entrant's profit function (as a price taker) becomes:

$$\pi_j = v_i A - v_j V_j - 2a + (2a - m_i - m_j)\varphi(V_j)Q \qquad (14)$$

First order conditions with respect to V_j, valid whenever $2a > m_i + m_j$, give[12]:

$$\varphi'(V_j) = \frac{v_j}{(2a - m_i - m_j)Q} \qquad (15)$$

We see that the new entrant's optimal coverage under the Variant 2 model is dependent on two margins: the margin between the national roaming access price and the marginal cost of traffic on both the new entrant and the host incumbent network. The first determines the national roaming outpayment savings that the new entrant will receive by expanding its network coverage, whilst the second (which does not occur under the Variant 1 model) in the loss in national roaming profit that the incumbent passes through to an increase in the market retail price. Thus, by expanding its network, the new entrant has a detrimental effect on the incumbent, and so causes a rise in the retail price.

For this reason, new entrant network coverage under the Variant 2 model will always exceed that under the Variant 1 model, whenever the national roaming access price exceeds the marginal cost of traffic of the host incumbent network. Mathematically, this is can be seen from comparing equations (9b) and (15) and noting that $\varphi''(V_j) < 0$ and $2a - m_i - m_j > a - m_j$ whenever $a > m_i$.

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12 Second order conditions are easily checked:

$$\frac{\partial^2 \pi_j}{\partial V_j^2} = (2a - m_i - m_j)\varphi''(V_j)Q < 0 \qquad \text{if } 2a > m_i + m_j$$

Taking the specific functional form in equation (8), we have:

$$V_j = A\left[1 - \frac{\gamma}{1+\gamma}\frac{v_j}{\left(2a - m_i - m_j\right)}\frac{A}{Q}\right]^{\frac{1}{\gamma}} \tag{16}$$

Chart 3 shows the new entrant's optimal coverage as a function of the national roaming access price. As expected, the coverage is always higher under the Variant 2 model, since the new entrant finds that it can increase the retail price by enlarging its own network and so reducing the amount of roaming profit that the host incumbent receives.

We are primarily interested in the level of a that will ensure the competitive neutrality between the two network, i.e. $\pi_i = \pi_j = 0$, assuming that both networks invest optimally (efficiently) in geographic network roll-out. Solving this problem with the assumption of Table 1 gives a value $a = 6.2$ ppm with coverage of $V_j = 75\%$ by the new entrant network, consistent with a point on Chart 2. As anticipated the Variant 2 calculates a larger network roll-out, and a corresponding higher national roaming access price compared to the Variant 1 model. It should also be noted that this optimal and competitive neutral national roaming charge (at 6.2 ppm) is significantly higher than the average cost of traffic on the host incumbent network, which can be calculated under assumptions of Table 1 as 4.5 ppm excluding roaming traffic, or 4.25 ppm including roaming traffic. This difference is a result of the restricted geographical coverage of the new entrant network, which means that national roaming is only required in lower traffic density areas of the host incumbent's network.

4. Conclusion

This paper has proposed a practical model that can be used to calculate optimal and competitive neutral national roaming access prices. This method takes account of the geographical cost structure of the networks, and thus allows for the "cream-skimming" effect whereby a new entrant will concentrate its own network build in low cost (higher traffic density) urban areas, especially when its uses a technology that has a cost advantage in these areas (e.g. WCDMA 2.1 GHz).

Both networks will invest in more geographic coverage when the national roaming access price is set higher – the incumbent will do so because of the extra revenue it will get from roaming charges, and the new entrant will do so in order to avoid paying roaming charges to the incumbent.

The paper provides an illustration of how the method could be applied to a situation where the host incumbent is restricted to GSM 900 against a new entrant deploying WCDMA 2.1 GHz. Under realistic assumptions we have calculated that a competitively neutral national roaming access price will be about 38% above the average cost on the host incumbent's network, although this result will depend on the specific distributions of traffic against geography in the country concerned. An access price set at this level will ensure competitive neutrality between networks, and provide efficient investment signal for the new entrant network.

The model could be adapted to the situation where the host incumbent also has access to WCDMA 2.1 GHz. This would require a more complex composite cost function, but with essentially the same model, which has not been attempted in this paper in the interests of clarity. Although the new entrant would no longer have a cost advantage in urban areas, it would nevertheless benefit from using the host incumbent's network in higher cost rural areas.