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Would David be more likely to speak to Angela under national roaming?

Adriano Basso and Pietro Crocioni



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## **Abstract**

The UK Government has proposed national roaming to ensure that consumers may use rival mobile networks in areas where their own operator does not offer (network) coverage (these are known as “partial not-spots”). The proposed policy aimed at increasing the likelihood of mobile subscribers being able to make and receive calls. While this may raise a number of issues, including the risk of higher prices via higher costs and collusion, this article focuses on only one question: whether national roaming, rather than making it more likely that consumers in partial not-spots may be able make and receive calls, may achieve the very opposite outcome. This is because, under national roaming, and depending on the level of the charge, mobile operators may have the incentive to withdraw their network coverage and roam instead.

## **Keywords**

Mobile; national roaming; investment incentives; coverage.





## 1. Introduction\*

The issue of mobile not-spots has been discussed for some time in the UK. However, it only came to the forefront of UK communications regulatory policy in the summer of 2014, supposedly when the UK Prime Minister David Cameron, on holiday in Cornwall, suffered a dropped call whilst talking to the German Chancellor, Angela Merkel.<sup>1</sup>

In the UK, four mobile network operators compete to provide services to consumers. They differentiate their services over a number of features, including their network coverage. As a result, there are areas of the UK where all of the networks are present (full coverage), areas where only one or few provide coverage (partial not-spots), and some where no network provides any coverage at all (full not-spots). The UK government aimed at reducing both types of not-spots. It decided to reduce full not-spots via a subsidy to increase coverage and proposed national roaming as a way to reduce the effects of partial not-spots. National roaming would not aim to increase the coverage of all networks; instead it would allow subscribers of networks which do not have coverage in partial not-spots to access the network of their competitors. To our knowledge, national roaming has not been introduced as a way to address partial not-spots anywhere. While national roaming has been adopted in many countries, it was designed to help new entrants by allowing them to offer a similar coverage to incumbents from the outset. Hence, it was an entry assistance policy, while national roaming for not-spots is better thought of as a consumer policy, whose aim was to maximise the probability that consumers could make and receive calls. Not only is the economic welfare case for regulatory intervention to cover partial (and full) not-spots unclear, but it could also have a number of unintended negative welfare consequences – e.g. reducing the scope for non-price competition, facilitating coordination and increasing costs and, ultimately, the retail prices faced by consumers. This article, however, is not concerned with the welfare implications of national roaming. Instead, we explore whether national roaming could provide incentives for operators to reduce either the scope of their network coverage or their quality and, as a result, make it less likely for consumers to make and receive calls. In other words, we examine whether or not it could achieve its declared policy objective.

We first provide some background information in Sections 2 and 3. We then examine the relevant literature in Section 4. This literature has focused on either the use of roaming as a collusive device, or has examined the equilibrium outcomes, including the impact on investment, with and without roaming. It is assumed that the networks know before undertaking the investment whether or not roaming will be available. Our approach differs from the existing literature in a number of ways. First, we assume that the regulator sets the charge, rather than this being endogenous. We then examine the policy outcomes in terms of incentive to retain, expand or reduce the scope and/or quality of coverage, depending on the level of the charge. This has a direct impact on the probability that consumers can make and receive calls. Second, national roaming is introduced when networks have already invested in coverage, not before investment. Hence, we focus on the effects of the charge on pre-existing patterns of investment – i.e. separately for partial not-spots and full coverage areas. Third, we take into account not only the competition between networks, but also the supply-side, by looking in detail at cost considerations. We consider our approach to have a particularly strong practical application and

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<sup>1</sup> See Millett, C., “Mobile networks pledge to slash ‘not spots’ in £5bn deal”, *Mobile*, 2 February 2015, available at <http://www.mobiletoday.co.uk/news/industry/32046/mobile-operators-pledge-to-slash-not-spots-in-5bn-deal.aspx#.VakXntFRHX4>.

to add to the existing contributions. We focus first on the effects irrespective of the structure of the roaming charge, while we provide some high-level considerations on the effects of linear and two-part tariffs (Section 5). We also explore the ways in which the incentives may change when one provider has a coverage obligation (Section 6). Our concluding remarks and further areas of research are confined to Section 7.

## 2. Background

### “Not-spots”

The areas not covered by any mobile network are known as full not-spots. In these locations, no consumer can make and receive calls. The term ‘partial not-spots’, instead, describes areas where some, but not all, mobile networks provide coverage – i.e. only some consumers can use their phone in the area, depending on which operator they subscribe to. The areas covered by all networks are instead known as full coverage areas.

Each of the three UK 2G mobile networks covers a similar proportion of UK premises (a proxy for population) and geography (see Table 1).

**Table 1: 2G mobile (outdoor) network coverage\***

	<b>O2</b>	<b>Vodafone</b>	<b>EE</b>
<b>Premises</b>	99%	99%	98%
<b>Geographic</b>	78%	82%	78%

Source: Ofcom, *Infrastructure Report 2014*, Figure 39, available at <http://stakeholders.ofcom.org.uk/binaries/research/infrastructure/2014/infrastructure-14.pdf>.

\* Three only has a 3G network.

However, although 99% of premises have 2G mobile coverage, networks do not perfectly overlap. As a result, partial (2G) not-spots cover about 3% of premises and 21% of geographical areas (see Table 2). 3G coverage (which is more relevant for data services than for calls) is much lower and, therefore, there is a higher proportion of 3G partial and full not-spots.

**Table 2: 2G and 3G full and partial not-spots**

	<b>Full not-spots</b>	<b>Partial not-spots</b>	<b>Full coverage</b>
<b>2G – Premises</b>	<1%	3%	97%
<b>2G – Geographic</b>	11%	21%	68%
<b>3G – Premises</b>	1%	15%	84%
<b>3G – Geographic</b>	22%	52%	26%

Source: Ofcom, *Infrastructure Report 2014*, Figure 41 and 47, available at <http://stakeholders.ofcom.org.uk/binaries/research/infrastructure/2014/infrastructure-14.pdf>.

### ***The UK Government's proposal***

The UK government set aside £150m in subsidies for mobile full not-spots, covering the necessary infrastructure as part of the so-called Mobile Infrastructure Project (MIP).<sup>2</sup> On partial not-spots, instead, the UK Government pushed for a national roaming remedy by threatening to legislate on the matter. The proposed policy was similar, in spirit, to international roaming arrangements, in that they are both symmetric relationships – i.e. each network supply and demand roaming. However, national roaming was voluntary rather than mandatory and, more importantly, while there are absolute entry barriers to roll-out a network in another country (i.e. a licence is needed), entry is always possible in case of national roaming for not-spot areas.

Mobile operators, though, strongly opposed national roaming. According to them,<sup>3</sup> it would (1) undermine investment in radio spectrum and equipment; (2) undermine the ability to differentiate amongst their products; (3) raise technical difficulties, such as a higher risk of dropped calls, worse battery life and difficulties in providing voicemail; and (4) undermine the lawful use of voice call intercepts.<sup>4</sup> At the end of 2014, all four UK networks signed a legally binding agreement to improve their network coverage, giving Ofcom the powers to enforce the terms of the agreement. In exchange, the Government would not legislate to impose national roaming.<sup>5</sup>

### **3. The partial not-spots issue**

In partial not-spots, only the subscribers of some operators are able to use their mobile phone. The national roaming option that was proposed by the UK Government would allow those subscribing to other networks to roam on rival networks. This would certainly benefit these consumers by increasing the probability that they will be able to make and receive calls, although it also carries risks of costly unintended consequences. First, coverage is a feature on which mobile networks compete and removing differences across networks would reduce the scope for coverage competition. This, in turn, may facilitate retail coordination between networks (Fabrizi and Wertlen 2008). Second, the costs of supplying roaming for the operators (inclusive of the reduced profits from the loss of service differentiation) could be larger than the value they can create and capture by extending their services into partial not-spots. If the networks are not compensated for this increase in costs, these are likely to be passed on, at least in part (depending on the nature of the costs and the intensity of competition),<sup>6</sup> to consumers, as higher prices and/or lower service quality. Third, it is also possible that national roaming would change the incentives of operators to maintain the current scope or quality of their network coverage. The concern is that, under certain circumstances, a roaming obligation may result in: 1) partial not-spots becoming full not-spots; 2) full coverage areas becoming partial, or even, full-not-spots; and 3) networks having reduced incentives to invest relative to a situation where roaming is

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<sup>2</sup> See Ofcom, “Government announces investment to increase mobile coverage”, available at <http://stakeholders.ofcom.org.uk/market-data-research/market-data/communications-market-reports/cmr12/telecoms-networks/uk-5.20and5.21>. See also Hirst D, “Mobile Coverage in the UK: Government plans to tackle ‘mobile not-spots’”, House of Commons Briefing Paper (9 June 2015).

<sup>3</sup> The UK Government consulted on four options including, in addition to national roaming, infrastructure sharing, allowing Mobile Virtual Networks (MVNOs) to access multiple networks and resell mobile services and a coverage obligation. See DCMS, “Tackling Partial Not-Spots in Mobile Phone Coverage”, consultation Document, 5 November 2014, available at [https://www.gov.uk/government/uploads/system/uploads/attachment\\_data/file/370808/formatted\\_condoc\\_final.pdf](https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/370808/formatted_condoc_final.pdf).

<sup>4</sup> See Millett, footnote 1.

<sup>5</sup> See Hirst D., footnote 2.

<sup>6</sup> For a review, see RBB (2014) and Alexandrov and Koulayev (2015).

absent, even without coverage withdrawals.<sup>7</sup> All these effects may reduce the likelihood of consumers being able to make and receive calls and are the focus of this article.

### ***A national roaming obligation***

Technically, roaming is a well-established mechanism, either as international or in some cases as national roaming. The former has been in operations for decades; it is a symmetric mechanism whereby operators offer each other roaming when their customers happen to be outside the country covered by the network they subscribe to. The ability to roam abroad is a complementary service to those the networks offer in their own country. It works in most cases by picking up and selecting the network with the strongest signal. The latter, instead, can be described, in most cases, as a temporary entry assistance measure often mandated by the regulator. In almost all cases the rationale was to temporarily assist new entrants in competing from the start on an equal footing with incumbents who had been licensed earlier-on and, hence, who already had an extensive network coverage. It was often mandated only for a limited period of time, and often at a relatively high wholesale charge, in order not to dis-incentivise the new entrant from rolling-out its network. The services provided through national roaming are substitutes to those offered by incumbent network operators. Furthermore, national roaming is an asymmetric measure which raises standard access issues.

National roaming for not-spots shares some similarities with standard national and international roaming obligations, but there are also important differences. Like international roaming, but unlike the standard national roaming entry assistance, it is a symmetric policy – i.e. every network would be able to roam on a competitor’s network, but only in a partial not-spot. It differs from international roaming in that the provider and user of roaming services compete with each other, hence, their services are substitutes and not complements. As far as we are aware, national roaming has not yet been applied or mandated to address partial not-spots.<sup>8</sup> Although the UK Government did not provide the exact details of its proposal, in this article we consider a specific type of national roaming obligation – i.e., a must-offer/must-take obligation (henceforth “national roaming obligation”). Each mobile network operator will be under the obligation to:

- offer roaming services to all other networks (must-offer obligation); and
- roam where its network does not have coverage (must-take obligation).<sup>9</sup>

The geographical scope may vary. In order to ensure that consumers subscribing to all networks can use their mobiles in partial not-spots, a national roaming obligation is only needed to operate in partial not-spots (“targeted” option). It could take the form of an obligation that only applies to some sites (used as proxies for not-spot areas).<sup>10</sup> Our understanding is that it may be technically possible to restrict roaming obligations to some sites. However, it is unlikely that a perfect match between targeted regulation and current not-spots can be achieved, and thus there will still be scope for a

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<sup>7</sup> Depending on the level of the charge, national roaming could also provide incentives for an operator to extend coverage into some full not-spots. These areas would not support one network, but this could become profitable if it were also able to sell roaming to its rivals’ customers. However, given the government subsidies programme via the MIP, networks are unlikely to have incentives to do so without the subsidy.

<sup>8</sup> DCMS (see footnote 3), para 74, mentions some limited examples in France and Australia.

<sup>9</sup> An alternative form of national roaming obligation could specify a must-offer obligation, but not a must-take obligation. Although this alternative approach is not discussed in the article, the main differences from the must-offer/must-take approach are presented in footnotes along the text. As will be seen, a must-offer-only obligation is likely to be inferior in its ability to reaching the policy’s objective.

<sup>10</sup> There are two possible sub-options. First, the obligation may only apply to current partial not-spots – i.e., any new future not-spots would not be included. Second, it could apply to partial not-spots at any point in time. This means that the extent of partial not-spots will have to be periodically reassessed.

network operator to roam on another even in areas where it has network coverage.<sup>11</sup> Alternatively, a “nationwide” option could take the form of an obligation to take roaming when the network’s own signal is below a minimum threshold. Although this might be simpler to implement (e.g. would not need to be dynamically adjusted over time) and is probably less technically complex, any potential risks from unintended consequences will be significantly more substantial as they will extend beyond the not-spot areas and apply to the entire network coverage. Critically, under both options, there is the possibility that roaming will occur even outside partial not-spots in so-called full coverage areas. In Section 5 we therefore consider the possible effects of a national roaming obligation, separately in partial not-spots and in full coverage areas.

#### **4. Relevant literature**

We are not aware of any formal study on how a regulator should set national roaming charges to avoid a reduction in existing networks’ coverage scope or quality.<sup>12</sup> However, there are two closely related strands of literature.

First, there is extensive literature on the relationship between one-way access charges and network investments – for an introduction see Valletti (2003a), while Cambini and Jiang (2009) provide a useful literature review in the context of broadband investments. Roaming charges are a type of access charge, although in a two-way access context that is more akin to reciprocal termination. A more specific access problem, which has in common with our paper the fact of finding conditions under which a Prisoner’s dilemma arises, is studied by Ordober and Shaffer (2007) and Bourreau et al. (2011), who consider the problem faced by vertically integrated network operators (e.g. MNOs) that must decide whether to give access to a downstream competitor (e.g. an MVNO).

Second, a few articles consider the specific issues related to national roaming and its implications for investments in mobile networks.<sup>13</sup> This article is an addition to this small literature. While there are several points of contact between the present article and earlier works, to our knowledge this is the first attempt to examine the impact of national roaming for partial not-spots on mobile coverage.

One of the first articles to investigate the relationship between national roaming and investment is Foros et al. (2002). The authors consider a three-stage model in which two mobile networks first agree on roaming quality, then choose their network investments (either cooperatively or non-cooperatively), and, finally, compete à la Cournot offering a homogeneous product. Roaming is interpreted in a wider sense than simply in terms of geographical coverage: for example, customers can use the infrastructure of the rival network in case of congestion. Customers’ willingness to pay increases with investments in their network; in the case of roaming, it also increases with the investments made by the other network. This can be seen as an investment spill-over, where roaming increases the quality of the services that each network offers to its customers and the customers’ willingness to pay. However, it is assumed not to affect the intensity of competition between networks. As a result, firms always choose to roam. The impact of roaming on network investment depends on whether or not they coordinate their investment decision. When they do so, mobile networks fully internalise the externality that, through roaming, competitors’ investments have on the quality offered by their own network. Investment levels are therefore higher than if roaming were not allowed. If investments are, instead, not coordinated, externalities are not taken into account, while each network

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<sup>11</sup> This is also because it is unlikely that the sites (to which a targeted obligation to roam would ultimately apply) perfectly match the geography of partial not-spots.

<sup>12</sup> The only article we are aware of that deals with partial not-spots considers their economic and social impact in the affected areas in the UK (Lu et al., 2014). They conclude that the availability of mobile services may affect the long-term sustainability of rural communities and may be an important factor in ensuring their economic diversity.

<sup>13</sup> Similar issues emerge in the context of ATM Networks. See McAndrews (2003) for a literature review.

has an incentive to free ride on the other's investments, leading to under-investment if compared to the case of no roaming.

Stühmeier (2012) further develops the model by Foros et al. (2002), introducing a roaming charge, either one set by the regulator or one that is jointly determined by the networks in the first stage of the game. He also allows, as in the present article, for coverage decisions to be endogenous, and examines the incentives to invest under discrete levels of the roaming charge set by the regulator. He finds that the incentive to expand or reduce coverage depends on the level of the roaming charge. The model differs from the approach developed in this article as it assumes that roaming rules are set before networks take investment decisions, while we assume that networks have already made coverage investment decisions and that they reassess these when roaming is introduced. Stühmeier (2012) also assumes that coverage is costless, while coverage costs and the way they are likely to differ across locations play a crucial role in our analysis.<sup>14</sup>

Fabrizi and Wertlen (2008) develop a model where mobile networks compete à la Hotelling. As in Foros et al. (2002), the networks always choose to roam. In this model, however, the purpose of a roaming agreement is mainly that of inflating prices through high reciprocal roaming charges. It is interesting to note that, in this model, the existence of a roaming agreement leads to the elimination of full not-spots. This result, however, crucially depends on the assumption of constant costs per unit of population. More importantly, the authors find that national roaming leads to networks not overlapping at all. There are, therefore, just partial not-spots where networks roam on each other.

In both Foros et al. (2002) and Fabrizio and Wertlen (2008), mobile networks always choose to roam. The result, however, depends either on the assumption that networks offer a homogeneous product, or, similarly, that customers do not value the extent of a network's coverage. Valletti (2003b), on the other hand, assumes that networks vary in their coverage and that customers, moving between different areas, view different levels of coverage as different quality levels. We make a similar assumption. In Valletti (2003b), roaming reduces network differentiation and, as a result, increases price competition. It follows that competing firms do not have an incentive to reach a roaming agreement. Colluding firms, on the other hand, can use roaming charges to redistribute profits in order to sustain monopoly prices, as in Fabrizio and Wertlen (2008).

Finally, Sandbach (2009) develops a model with which to determine how roaming could be regulated to facilitate entry in a way that does not dis-incentivise network investment. Unlike in Sandbach (2009), we assume that in partial not-spots dual coverage is unprofitable.

Our approach combines features from some of the models discussed above: it studies the relationship between roaming charges and the incentives to invest in coverage, as does Stühmeier (2012), but in the context of network differentiation, as in Valletti (2003b). Our approach is simple in that we do not formally model demand and do not develop an equilibrium model. We consider that our model, however, better reflects the reality of a possible introduction of a national roaming obligation for not-spots. First, roaming charges are set by the regulator and are not endogenous. Second, we consider the effect of national roaming after networks have already invested in coverage and sunk their costs. Third, we define the roaming charges' thresholds at which the scope of coverage and its quality may be negatively affected relative to pre-roaming and we identify the variables that are required to set such a threshold. This allows us to take into account the geographical heterogeneity of demand and supply conditions.

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<sup>14</sup> On the other hand, Stühmeier (2012) takes into account the impact of roaming on retail prices and the incentives this generates, which we do not directly consider.

## 5. The base model

### *Assumptions*

We make some simplifying, but realistic, assumptions on the number of mobile networks, the type of areas, the actions that mobile networks can take, and their cost structures.

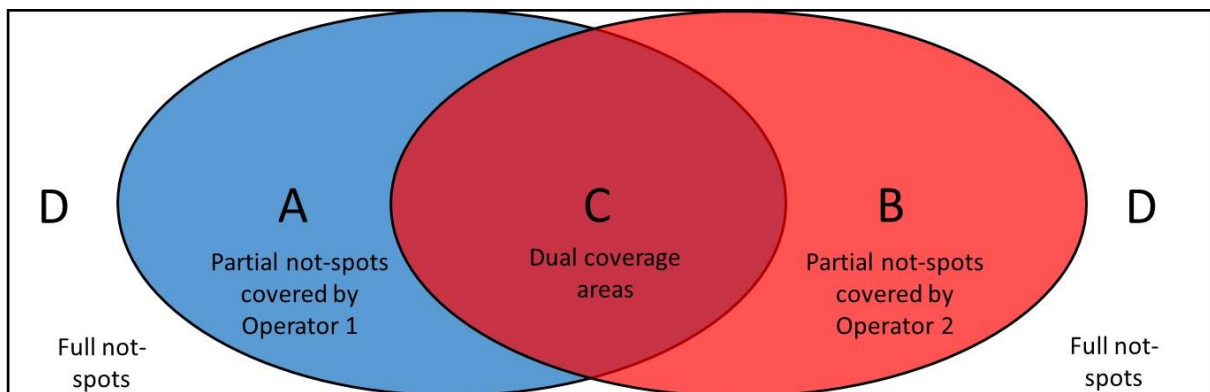
### *Networks and area types*

The analysis is aimed at evaluating national roaming as an instrument to increase the likelihood that consumers are able to make and receive calls. Therefore, we consider a situation in which, before the introduction of national roaming, operators have already rolled out their networks. In particular, we assume that they have done so in all the areas where it was profitable to do so. We assume that there are only two mobile network operators: Operator 1 and Operator 2. Before a national roaming obligation is introduced, we can distinguish between the following area types (Figure 1):

- partial not-spots covered by Operator 1, but not by Operator 2 (area A), and others covered by Operator 2, but not by Operator 1 (area B). These are areas where the level of demand makes the existence of one network profitable, but does not justify rolling-out a second one;<sup>15</sup>
- dual coverage areas served by both operators (area C). These are areas where demand is sufficiently high to make two networks profitable; and
- full not-spots (area D) covered by neither Operator 1 nor Operator 2. There is insufficient demand to justify rolling-out a network in these areas.

We focus on the impact of a national roaming obligation on partial not-spots and dual coverage areas, while we do neither model nor discuss the impact of the roaming obligation on full not-spots.

**Figure 1: Area types**



### *The regulator sets the national roaming charge*

We assume that national roaming is mandated. We consider this is a sensible assumption, given the mobile operators' strong opposition to this measure. We also assume that the regulator sets a wholesale roaming charge. If left to commercial negotiations, an agreement may not be reached, or, if it is reached, may not benefit consumers. For instance, if operators' positions are similar in terms of their network coverage (e.g. they supply national roaming to each other in a balanced way), they may

<sup>15</sup> We assume that partial not-spots are not a temporary phenomenon. This seems realistic given that there are still partial not-spots today (Table 2) two decades after the introduction of 2G.

agree to set high wholesale reciprocal roaming charges that are likely to feed into higher retail prices for consumers, as in Fabrizi and Wertlen (2008). Alternatively, if the network positions are asymmetric, the larger operator will have to supply roaming in more instances than those in which it will have to purchase it. It may, therefore, have incentives and be able to set higher wholesale roaming charges for operators with smaller network coverages.<sup>16</sup>

### ***Timing of the game and possible actions***

Our basic model describes the networks' interaction as a simultaneous game. When a national roaming obligation is introduced, either Operator 1 or Operator 2 can only take the following actions:

- Withdraw its network. In a partial not-spot, this will result in no coverage. In dual coverage areas, the withdrawing operator would rely on roaming, if the other operator maintains its coverage; the result is no coverage if both operators decide to withdraw;
- Continue to cover the area and, if this is a partial not-spot, offer roaming. Depending on the level of the roaming charge and the cost of providing roaming, operators may either have sufficient incentives to invest and maintain the current quality of their network (and services), have an incentive to reduce, or even increase their network quality; or
- Extend the coverage of its network to cover the area. For example, in a partial not-spot, an operator that does not cover the area may come to the view that it would be better-off rolling out its own network than roaming on the rival network.<sup>17</sup>

Our base assumption is that, in response to the introduction of national roaming, operators take a decision and commit to it. If networks could be easily switched on and off in a local area, then their interaction could be modelled as a repeated game, rather than as a simultaneous one. We briefly discuss this possibility at the end of this Section.

### ***Costs***

In our analysis, we refer to three key types of local – i.e. related to activities and actions taken by a network in a particular area – costs. We considered the present discounted values of:

- $C_{\text{Roa}}$  – the incremental cost of offering roaming, if the operator already covers the area;<sup>18</sup>
- $C_{\text{Roll}}$  – the cost of rolling-out the network to cover the area, if the operator does not already cover it; and
- $C_{\text{NoRoa}}$  – the costs of providing retail mobile services in an area relying on one's own network.

### ***Partial not-spots***

Consider a partial not-spot that is covered by Operator 1 (a site belonging to area A in Figure 1). Only one network can be profitable, otherwise we would expect both operators to cover the area, and this to

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<sup>16</sup> There is a substantial amount of literature on the conditions under which telecommunication networks have incentives and are able to set their termination rates collusively. See, for example, Armstrong (1998), Cambini and Valletti (2008), Laffont, Rey, and Tirole, (1998a), Gabrielsen and Vagstad (2008).

<sup>17</sup> From a welfare perspective, an increase (or decrease) in coverage and/or its quality, as a result of the introduction of national roaming, could either be positive or negative. However, in this article we are only focusing on whether a reduction in coverage (or its quality) will reduce the likelihood of consumers being able to make and receive calls.

<sup>18</sup> These costs are incremental to those to provide other types of roaming. To provide roaming for not-spots networks will need to adjust their equipment in the relevant areas (it could be hundreds if not thousands of small areas).



be a dual coverage area.<sup>19</sup> Depending on the level of the charge, a national roaming obligation may provide the operator with incentives to withdraw its network, extend its coverage or to reduce its investment and result in lower service quality.

For ease of exposition, we first assume that the only profit contribution from covering a partial not-spot is from local traffic. We discuss below how the results can be extended and generalised.

We first consider the level of the roaming charge at which Operator 1 has an incentive to retain exactly the same scope and quality of coverage that it had pre-roaming. We denote the roaming charge as  $P_{Roa}$ . This is expressed as the present discounted value of expected roaming revenues. The key variables through which to understand Operator 1's incentives are the following.<sup>20</sup>

- $C_{Roa}$  = incremental local cost of providing roaming;
- $\pi_{NoRoa}$  = the local profits pre-roaming obligation; and
- $\pi_{Roa}$  = the local profits post-roaming obligation - other than the profits from roaming ( $P_{Roa} - C_{Roa}$ ). This could be lower than  $\pi_{NoRoa}$ , if, post-roaming obligation, some of Operator 1's customers in the area switched to Operator 2.

All variables are expressed as present discounted values.

Following the imposition of a national roaming obligation, if Operator 1 retains its network, it will have to offer roaming, making a roaming profit of  $(P_{Roa} - C_{Roa})$ , while its local profits will change and, most likely, decline to  $\pi_{Roa}$ . Operator 1 will be in the same position both pre- and post-roaming, if its profits post-roaming are identical to those before the roaming obligation:

$$\pi_{Roa} + P_{Roa} - C_{Roa} = \pi_{NoRoa}$$

Defining  $\Delta\pi_{Roa} = \pi_{NoRoa} - \pi_{Roa}$ , this is the case if:

$$P_{Roa} = C_{Roa} + \Delta\pi_{Roa}$$

At lower levels of  $P_{Roa}$ , Operator 1 retains coverage if  $P_{Roa}$  is such that, post-roaming obligation, it still makes a profit:<sup>21</sup>

$$\pi_{Roa} + P_{Roa} - C_{Roa} > 0$$

This is the case as long as:

$$P_{Roa} > C_{Roa} - \pi_{Roa}$$

Note that the right hand-side may be negative (if  $\pi_{Roa} > C_{Roa}$ ) and, hence, Operator 1 may have incentives to retain its network even if the roaming charge is set at zero (we rule out negative roaming charges). At these levels, Operator 1, though, will have a reduced incentive to maintain the quality of its coverage. Below this level, however, Operator 1 would make losses and would prefer to withdraw its network in order to avoid these.

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<sup>19</sup> By assumption, if Operator 2 entered, the post-entry prices would be too low to cover the fixed cost of entry. Partial not-spots sustain one network because either local traffic is insufficient to support two networks, or coverage of the spot may allow the network to charge a nationwide price premium or to attract additional subscribers (or a combination of the two).

<sup>20</sup> If it decided to withdraw its network, Operator 1 would incur some costs in dismantling the site, but it could also recover some cost if it could resell some of the equipment. For ease of exposition we have not considered these here.

<sup>21</sup> Note that we assume that  $C_{Roa}$  and  $\Delta\pi_{Roa}$  are (i.e., unaffected by the level of the roaming charge). This seems a reasonable assumption.

If  $P_{\text{Roa}} > C_{\text{Roa}} + \Delta\pi_{\text{Roa}}$ , instead, Operator 1 has an incentive to retain coverage and to invest in the local network, at least to the same degree as, but most likely more than, it did before the national roaming obligation was imposed.

As  $P_{\text{Roa}}$  increases it will reach a level at which it also affects Operator 2's incentives. Operator 2 must purchase roaming from Operator 1, unless it builds its own network. It prefers to do so when:

$$P_{\text{Roa}} < C_{\text{Roll}}^{22}$$

When the roaming charge is above this level, Operator 2 prefers to rollout a new network to avoid the roaming charges. If this were to occur, however, both operators would make losses, as two operators cannot be profitable in a partial not-spot area. To understand the outcome in this case, we make use of Table 3, which shows the pay-offs for Operator 1 ( $\pi_{\text{Op1}}$ ) and Operator 2 ( $\pi_{\text{Op2}}$ ) under each possible scenario. If Operator 1 withdrew its network and Operator 2 did not roll-out its own, they would both make zero profits.<sup>23</sup> If Operator 1 retained its network and Operator 2 rolled out its own, they would both incur a loss. The two asymmetric outcomes, in which only one network is present, are unstable because the other operator would also prefer to roll-out its own network. This is a classic Prisoner's dilemma, where both operators would be better-off if they could cooperate and agree to turn the area into a full not-spot. Without cooperation, dual coverage would be the only equilibrium. There will be two networks and, hence, Operator 2's subscribers could rely on their own operator's network where previously they could not. However, as both Operator 1 and Operator 2 would be making losses, they would have lower incentives to invest than Operator 1 had before a national roaming obligation was introduced. As a result, the networks' quality may be degraded.<sup>24</sup> Roaming on a single high quality network may be better for all consumers (if the roaming charge were set at a lower level). Furthermore, given that both mobile networks may have higher marginal (as well as fixed) costs, these could be passed-through into higher retail prices.

**Table 3: Operator 1's and Operator 2's pay-offs in a partial not-spot with  $P_{\text{Roa}} > C_{\text{Roll}}$**

		$\pi_{\text{Op1}}$	
		<i>Withdraw</i>	<i>Retain</i>
$\pi_{\text{Op2}}$	<i>Not roll-out</i>	0; 0	$\ll 0$ ; $> 0$
	<i>Roll-out</i>	$> 0$ ; $\ll 0$	$< 0$ ; $< 0$

To sum up, the level of the roaming charge affects the status of the partial not-spot area in terms of coverage, as follows (Figure 2):

- For a very low level of the roaming charge ( $P_{\text{Roa}} < C_{\text{Roa}} - \pi_{\text{Roa}}$ ), which may not exist, since  $P_{\text{Roa}}$  may have to be negative, the partial not-spot could become a full not spot.
- For  $P_{\text{Roa}}$  between  $C_{\text{Roa}} - \pi_{\text{Roa}}$  and  $C_{\text{Roa}} + \Delta\pi_{\text{Roa}}$ , Operator 1 has an incentive to retain its network, but not to invest in it to the same degree as it did pre-roaming obligation.

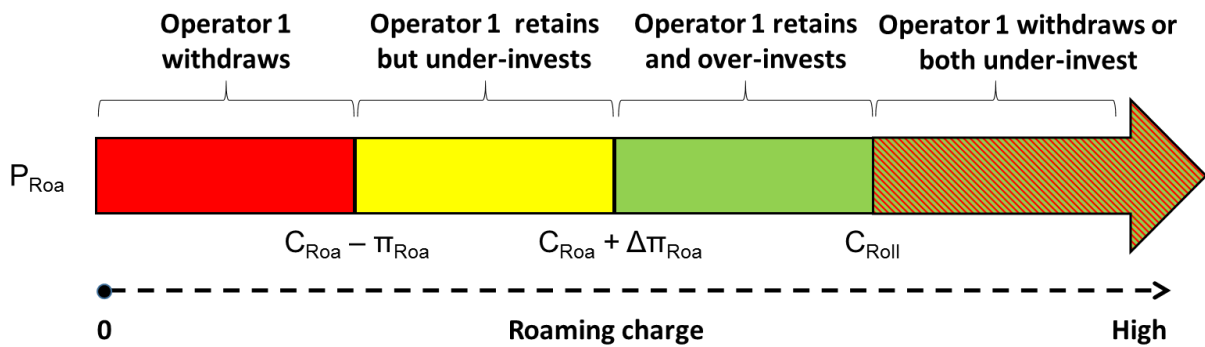
<sup>22</sup> Operator 2 would have incentives to roll-out its network if the profits were higher than in the case where it relied on roaming. Assuming that Operator 2's traffic, revenues and associated costs are the same, irrespective of whether it roams or rolls out its network (a plausible assumption), then it would have incentives to roll its network out if the cost of rolling out and maintaining its own networks were lower than the costs it would incur if it roamed.

<sup>23</sup> For simplicity, we abstract here from the proportion of costs invested in the network that Operator 1 could recover by withdrawing, which, instead, we consider in detail in the assessment of dual coverage areas. Taking these costs into consideration does not change the results of the analysis.

<sup>24</sup> We focus on investments that are necessary to maintain the quality of the network. For these investments, the reduced profitability of the area is likely to translate into lower returns. Our arguments do not necessarily apply to investments to improve the quality of the network.

- At a higher range ( $C_{\text{Roa}} + \Delta\pi_{\text{Roa}} \leq P_{\text{Roa}} < C_{\text{Roll}}$ ), Operator 1 has incentives to maintain the network and has at least the same incentives to invest in the network as before the roaming obligation was imposed.<sup>25</sup> This is the level at which a regulator should aim to set the roaming charge, if the aim was to increase the probability of callers to make and receive calls. As  $P_{\text{Roa}}$  increases above  $C_{\text{Roa}} + \Delta\pi_{\text{Roa}}$ , the quality of Operator 1's network may increase. However, there is no guarantee that this range exists. While it is highly plausible that  $C_{\text{Roa}} < C_{\text{Roll}}$ , if  $\Delta\pi_{\text{Roa}}$  is particularly large, this range may not exist.
- If the roaming charge is above  $C_{\text{Roll}}$ , then the partial not-spot could become a dual coverage area, but possibly with networks of lower quality, if the operators were unable to coordinate. Otherwise, the area could become a full not-spot.<sup>26</sup>

**Figure 2: Incentives in a partial not-spot**



An operator may decide to cover a partial not-spot area not only because it is locally profitable, but also because adding this area to the network increases the quality of its services over that of its rivals, allowing to price them at a premium. Continuing with this example, suppose the partial not-spot does not generate sufficient local revenues for Operator 1 to justify coverage, but it allows Operator 1 to charge higher prices nationwide for its coverage quality premium.<sup>27</sup>

The size of the gain from coverage in not-spots is likely to depend on a number of factors, including consumers' willingness to pay for coverage, and the difference in coverage between Operator 1 and Operator 2. If Operator 1 has a significantly larger network (Area A in Figure 1 is large, and much larger and more important profit-wise than area B), the surplus it could extract from its wider coverage may be substantial. Even if areas A and B were of similar 'size', there may still be an advantage for Operator 1; for example, it may simply cover a more valuable area.

Suppose Operator 1 has an advantage. If national roaming was introduced, operators would no longer be able to use coverage as a differentiating factor. This removes Operator 1's ability to extract additional gains and intensifies price competition. As additional profits from a national price premium disappear, Operator 1 will keep coverage locally only if local revenues cover the local costs. If not,

<sup>25</sup> If the roaming charge also applied to full not-spots, Operator 1 might even decide to extend its coverage to some of the full not-spot areas. These could become more attractive depending on the local expected revenues and network coverage costs. However, given the Government's MIP this may not be a relevant consideration.

<sup>26</sup> With a must-offer-only obligation, there is no risk of Operator 1 withdrawing its network. On the other hand, Operator 2 would not be willing to roam if  $P_{\text{Roa}}$  is higher than its revenue from additional traffic. This is likely to be the case for values of  $P_{\text{Roa}}$  much lower than  $C_{\text{Roll}}$ . Therefore, the likelihood that the policy would not reach its objective will be higher.

<sup>27</sup> Some consumers may particularly value the option to be able to use the phone in remote areas, or simply the large majority of consumers may not be aware of the exact locations of not-spots and will prefer to minimise the risk of finding themselves in a not-spot.

there is a risk that either the partial not-spot becomes a full not-spot (if Operator 1 and Operator 2 can cooperate) or there will be two networks of low quality.

Our overall results also apply to this situation, with the difference that  $\Delta\pi_{\text{Roa}}$ , the reduction in local profits caused by imposing a roaming obligation - other than revenues ( $P_{\text{Roa}}$ ) and costs ( $C_{\text{Roa}}$ ) from roaming - could now be much larger.<sup>28</sup> Although there may still be a range of values for the roaming charge whereby Operator 1 has an incentive to maintain coverage and not to reduce investment, this will be smaller than under the previous scenario. While the upper bound identified above is the same, the lower bound is higher.

### Dual coverage areas

If national roaming is not restricted to current partial not-spots, roaming may also occur where it should not - i.e. in (some) dual coverage areas.<sup>29</sup> Either mobile network may be better-off by withdrawing its coverage and, instead, roam on its rival's network. The concern is, therefore, that a dual coverage area may experience withdrawals following the introduction of a national roaming obligation. This may reduce the likelihood of consumers to be able to make and receive calls.

Consider a site that is covered by both Operator 1 and Operator 2 (Area C in Figure 1). For ease of exposition, let us assume that Operator 2 decides whether or not to roam, while Operator 1 'reacts' to its rival's decision. The full characterisation of the solution to the simultaneous game can be easily derived inverting the roles of the two operators. As for partial not-spots, we are interested in the investment incentives of Operator 2 and Operator 1, and in the likely outcome in terms of coverage as we vary the level of the roaming charge.

We assume that, before a national roaming obligation is introduced, both networks make positive profits in the area ( $\pi_{\text{NoRoa}} > 0$ ) and that, if an operator withdrew its network coverage, it could recover a proportion ( $\beta$  where  $0 \leq \beta \leq 1$ ) of the non-sunk local costs incurred to provide mobile services ( $C_{\text{NoRoa}}$ ). Once a national roaming obligation is introduced, if Operator 2 retains its network (and does not roam) it makes the same profits as before the introduction of the roaming obligation - i.e.,  $\pi_{\text{NoRoa}} > 0$ . If instead it decides to roam, we assume it withdraws its network. Its profits are adjusted downwards because it now has to pay to roam on Operator 1's network, and upwards because it can now recover  $\beta C_{\text{NoRoa}}$ . Post-roaming Operator 2's profits are therefore:

$$\pi_{\text{Roa}} = \pi_{\text{NoRoa}} - P_{\text{NoRoa}} + \beta C_{\text{NoRoa}}$$

Operator 2 would be in the same position pre- and post-roaming if its profits post-roaming are identical to those pre-roaming obligation ( $\pi_{\text{Roa}} = \pi_{\text{NoRoa}}$ ). This is the case if:

$$P_{\text{Roa}} = \beta C_{\text{NoRoa}}$$

As long as the roaming charge paid by Operator 2 to Operator 1 ( $P_{\text{Roa (Op1)}}$ ) is larger than Operator 2's recoverable local costs ( $\beta C_{\text{NoRoa (Op2)}}$ ), then Operator 2 will retain its network coverage. This is shown in Figure 3 by the area above the line  $P_{\text{Roa (Op1)}} = \beta C_{\text{NoRoa (Op2)}}$ . Note that even if Operator 2 and Operator 1 retained their networks, they may still have an incentive to reciprocally roam on each other's networks as the roaming charge is high and would allow them to increase retail prices in a similar way to the mechanism examined in Fabrizi and Wertlen (2008).

Suppose now that the roaming charge is sufficiently low that Operator 2 would prefer to withdraw its network and roam and, instead, consider Operator 1's incentives. This is shown by the area below

<sup>28</sup> In addition, since  $\pi_{\text{Roa}}$  is now likely to be negative, there might be a wider range of  $P_{\text{Roa}}$  at which Operator 1 would withdraw coverage.

<sup>29</sup> Clearly, under the nationwide option these effects would be much more widespread.

the line  $P_{\text{Roa}}(\text{Op1}) = \beta C_{\text{NoRoa}}(\text{Op2})$  in Figure 3. Operator 1's profits change because post-roaming it earns the revenues and incurs the costs of providing roaming:

$$\Pi_{\text{Roa}}(\text{Op1}) = \Pi_{\text{NoRoa}}(\text{Op1}) + P_{\text{Roa}}(\text{Op1}) - C_{\text{Roa}}(\text{Op1})$$

(for ease of exposition, henceforth we do not make use of the subscripts (Op1) and (Op2)).

There are three possible cases. First, if Operator 1's profits are increased above its pre-roaming level by Operator 2's decision to roam, Operator 1 prefers to retain its network. Instead of two networks there will be one (Operator 1). This is the case when:

$$P_{\text{Roa}} > C_{\text{Roa}}$$

This is shown in Figure 3 by the triangular area on the left hand-side. Second, suppose Operator 1's profits post-roaming are still positive, but lower than those it made pre-roaming (i.e.  $0 < \pi_{\text{NoRoa}} + P_{\text{Roa}} - C_{\text{Roa}} < \pi_{\text{NoRoa}}$  or  $C_{\text{Roa}} - \pi_{\text{NoRoa}} < P_{\text{Roa}} < C_{\text{Roa}}$ ). In this case, Operator 1 would be better-off retaining its network, but may have reduced incentives to invest if compared to the pre-national roaming obligation situation. Instead of two networks there will be one, possibly of lower quality. This is the area in the middle of Figure 3.

Last, suppose instead that Operator 1's profits post-roaming were negative – i.e. Operator 2's decision to roam made Operator 1 much worse-off than pre-roaming (i.e.,  $\pi_{\text{NoRoa}} + P_{\text{Roa}} - C_{\text{Roa}} < 0$ , that is,  $P_{\text{Roa}} < C_{\text{Roa}} - \pi_{\text{NoRoa}}$  – this is the right hand-side area in Figure 3). In this case, Operator 1 has an incentive to withdraw its coverage and it can make a credible threat to do so. To understand the outcome in this case, we make use of Table 4, which shows the pay-offs for Operator 1 ( $\pi_{\text{Op1}}$ ) and Operator 2 ( $\pi_{\text{Op2}}$ ) from retaining and withdrawing their network. If both withdrew their networks, they would make zero profits. If both retained their networks, then they would make at least the same profits as without national roaming.<sup>30</sup> The two asymmetric outcomes, with one network retaining coverage and one withdrawing it, are unstable because the operator who retains the network makes losses and would also prefer to withdraw. In other words, the roaming charge is sufficiently low that Operator 2 prefers to roam because it is very cheap, while Operator 1 does not want to offer roaming because it is so cheap that it makes losses by offering it. This is a Prisoner's dilemma, where both networks would be better-off if they could cooperate and agree to both retaining their networks. However, if they did not, both networks would be withdrawn.<sup>31</sup>

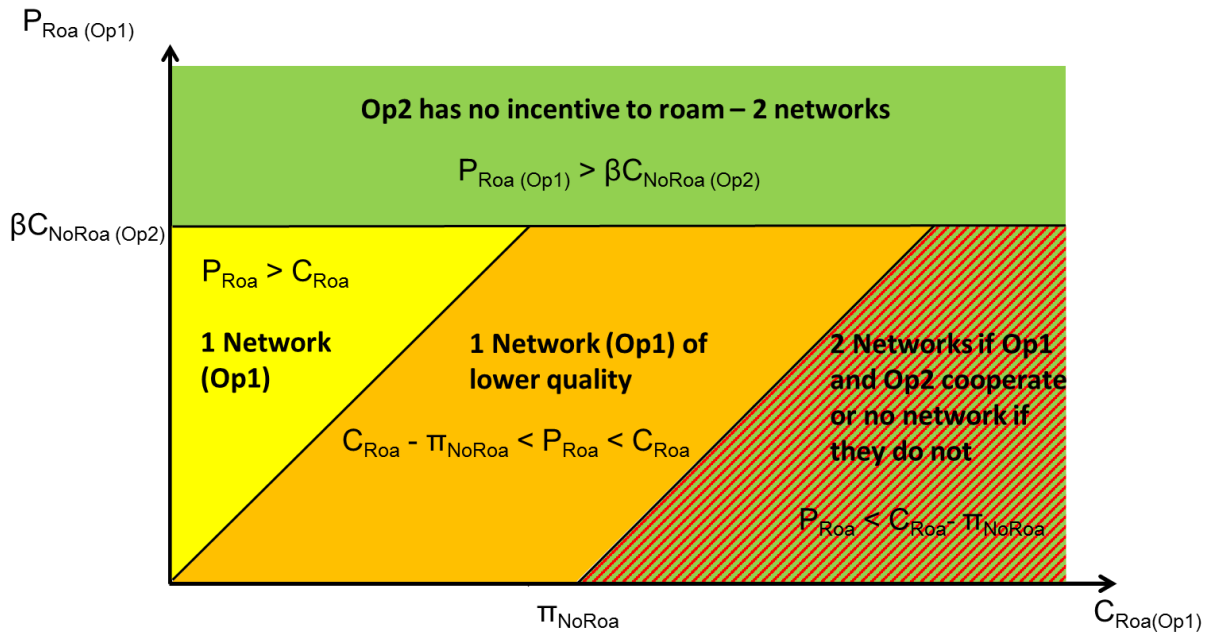
**Table 4: Operator 1's and Operator 2's pay-off for retaining or withdrawing the network**

		$\pi_{\text{Op1}}$	
		<i>Withdraw</i>	<i>Retain</i>
$\pi_{\text{Op2}}$	<i>Withdraw</i>	0; 0	>> 0; < 0
	<i>Retain</i>	< 0; >> 0	> 0; > 0

<sup>30</sup> If both Operator 1 and Operator 2 retain their networks this means that they may roam on each other's. However, if their roaming pattern is symmetric (i.e., Operator 2 does not roam more on Operator 1 than Operator 1 does on Operator 2) and  $C_{\text{Roa}}$  is not too high, they would be better-off than if both withdrew.

<sup>31</sup> In dual coverage areas, a must-offer-only obligation would not change the analysis.

**Figure 3: Incentives in dual coverage areas**



**The structure of the roaming charge**

We have so far abstracted from the structure of the roaming charge set by the regulator by focusing on the level of the charge. We now briefly consider how different roaming charge structures could affect the operators’ incentives about which coverage and quality to offer.

Setting a nationally uniform roaming charge is likely to be particularly complex. Even limiting the regulator’s objective to the minimisation of network withdrawals or degradation relative to the pre-roaming situation, it is likely that the probability of error remains high. First, the roaming charge is a single policy tool which needs to achieve two objectives - i.e. to minimise withdrawals in both partial not-spots and dual coverage areas. Both objectives may not necessarily be achieved with a single tool, and there will be trade-offs. Second, the operators’ decisions on whether or not to withdraw coverage are based on incentives at the local level. If local profits and costs vary significantly across areas, a geographically uniform roaming charge may work for some areas, but may provide operators with the wrong incentives in other areas.

Let’s examine first the partial not-spots. As many partial not-spots generate very little traffic, a linear (i.e. per-minute) roaming charge may often fail to generate sufficient revenues for the operator to retain coverage. The only way to ensure that coverage is retained is to set a single fixed charge whose level is targeted at each partial not-spot. This consists of a local subsidy from its rival that makes the operator better-off by retaining its coverage. However, unless the linear (or the fixed) charge is particularly (but not too) high, there would still be incentives to reduce coverage or to degrade the quality in partial not-spot areas where losses are particularly high.

In dual coverage areas, the roaming charge needs at least to cover the non-sunk costs of providing the network services ( $\beta C_{NoRoa}$ ) in order to prevent withdrawals. If the traffic level in the area is high, a linear charge, even one that is not too high, may be sufficient. Operators would have no incentives to withdraw coverage (or to degrade the quality of their networks). However, where traffic is low, sufficient revenues may be raised via either a high per-minute charge; or a two-part tariff made up of a linear component to cover the incremental costs of roaming, and a fixed contribution for each dual coverage area in which roaming traffic is higher than a given threshold.

Overall, assuming that only a single nationally uniform charge is practical, a two-part tariff applied to all (partial not-spots and dual coverage) areas is likely to be the most appropriate charge structure in order to limit the extent of network withdrawals or degradation. This could consist of a fixed charge covering losses in partial not-spot areas in order to maintain coverage, and a linear charge disincentivising coverage withdrawals in dual coverage areas. Even with this charge structure, however, the risk of regulatory failure would remain high. Determining the right level and structure for the charge (and updating it) is challenging, and, if the cost and revenue variation across areas is large, there is a substantial risk that a nationally uniform charge will fail to provide the right incentives in all areas.

### ***The effect of repeated interaction when networks can be switched-off and -on***

So far, we have assumed that the operators' decision to either maintain their coverage and offer roaming or withdraw from an area is irrevocable. This is implicit in assuming that the game has only one stage. If, however, networks can easily be switched-off – i.e. implying a low level of sunk costs - and -on in a local area, then the interaction between operators changes from a one stage simultaneous game to an infinitely repeated game. Such a framework requires a different type of analysis and has important implications on the effectiveness of the roaming obligation. While it is beyond the scope of this article to fully analyse a model with repeated interaction, we have drawn some high-level considerations.

Repeated interaction can potentially affect the outcome in those situations in which the roaming obligation gives rise to a Prisoners' Dilemma. As we discussed above, in a partial not-spot, when  $P_{\text{Roa}} > C_{\text{Roll}}$ , both networks would prefer an outcome in which coverage is withdrawn. In a one stage simultaneous game, however, the dominant strategy for the incumbent is to maintain its coverage and for the other operator to roll-out its network. The introduction of repeated interaction may facilitate coordination between the operators. If switching a network off and on is easy, so that interaction is frequent, the adoption of trigger strategies may allow the operators to coordinate on the mutually preferred outcome, that is, coverage withdrawal. In a one stage simultaneous game, in dual coverage areas, when the roaming charge is particularly low ( $P_{\text{Roa}} < C_{\text{Roa}} - \pi_{\text{NoRoa}}$ ), network withdrawal is a dominant strategy for the operators, although both would prefer an outcome in which coverage is maintained. When we introduce repeated interaction, coordination may also become possible, resulting in dual coverage being maintained.

Repeated interaction between networks can, therefore, limit the likelihood of the roaming obligation resulting in network withdrawal in dual coverage areas, but can increase the prospects of withdrawal in partial full-spots.

## **6. When one network has a coverage obligation**

In Sections 4 and 5 we assumed that each operator was free to withdraw its coverage, if it was better-off by doing so. This reflects the current situation for 2G and 3G services in the UK, where no network has a coverage obligation. However, one of the UK 4G licences has an extensive coverage obligation.<sup>32</sup> We now assume that Operator 1, who has a coverage obligation, can never withdraw its coverage, even if it made losses in the area after national roaming was introduced. This is a slightly simplifying assumption, since the operator may respond to a mandatory roaming obligation by removing coverage in some areas and meeting its coverage obligation by extending it in others.<sup>33</sup>

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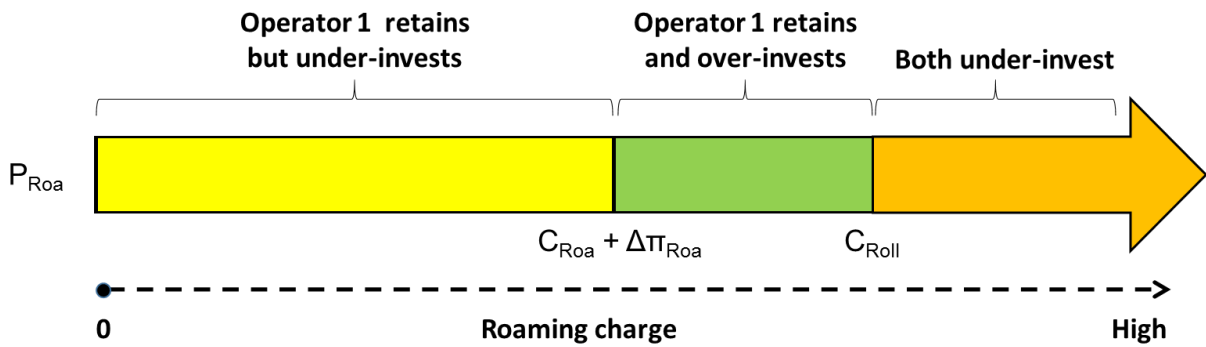
<sup>32</sup> Operator 1 is obliged to provide a mobile broadband service for indoor reception to at least 98% of the UK population (expected to cover at least 99% when outdoors) and at least 95% of the population of each of the UK nations – England, Northern Ireland, Scotland and Wales - by the end of 2017 at the latest.

<sup>33</sup> There may also be some (fewer) partial not-spots where the only network is that without a coverage obligation.

Consider first a partial not-spot where only Operator 1 is present. The critical thresholds identified in the base case in Section 5 and Figure 2 remain valid. However, Operator 1's choice set differs from the base case. Suppose that the partial not-spot is profitable. With a coverage obligation, if the roaming charge does not cover Operator 1's incremental costs of offering roaming, plus its expected profit loss (i.e.  $C_{Roa} + \Delta\pi_{Roa}$ ), Operator 1 can only react by refraining from investing, causing a deterioration of the quality of the service. The partial not-spot cannot, therefore, become a full not-spot, but it can become a partial not-spot with a network of lower quality if compared to the pre-national roaming obligation situation. Compared to our base case, the coverage obligation eliminates the risk that the area is turned into a full not-spot.

When the charge is higher than the cost of extending Operator 2's network over the not-spot area ( $C_{Roll}$ ), the outcome is the same as that obtained in our base case when the operators cannot coordinate their investments: the partial not-spot would become an area of dual coverage in which, however, both operators make losses, and they may invest less than Operator 1 did before the introduction of a national roaming obligation and, hence, quality may deteriorate. Figure 4 summarises these arguments.

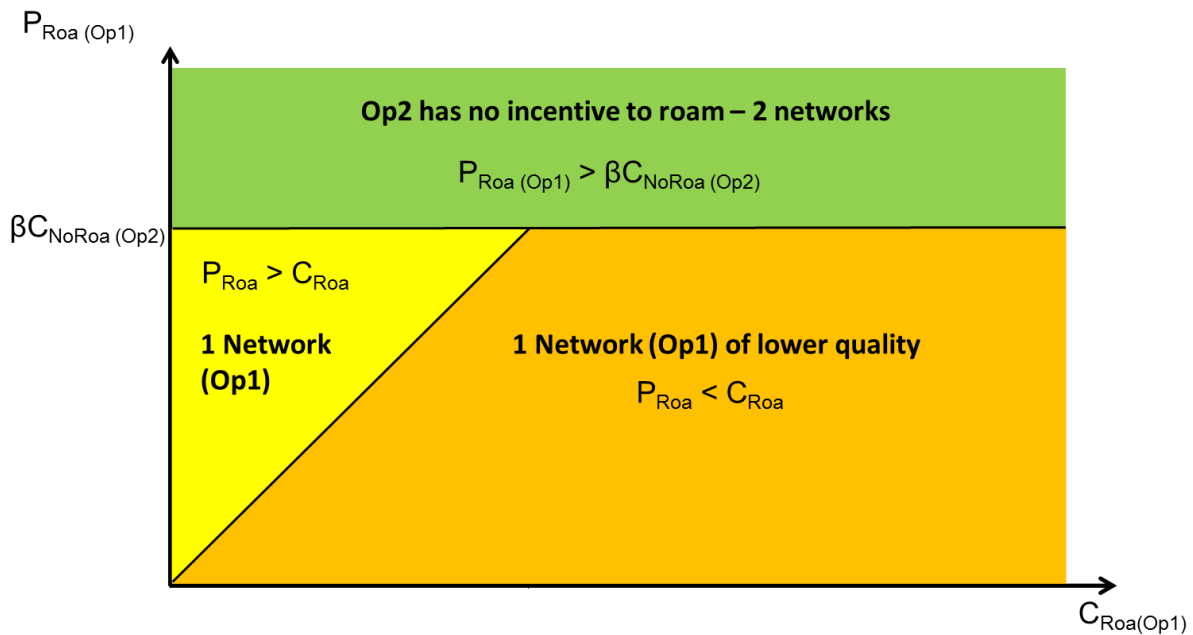
**Figure 4: Incentives in a partial not-spot with a coverage obligation on Operator 1**



A coverage obligation for one operator simplifies the assessment of the incentive structure also in dual coverage areas. Since Operator 1 cannot withdraw its coverage and rely on roaming, it is sufficient to consider whether Operator 2 has incentives to withdraw, and Operator 1's likely reaction, solely in terms of network quality's degradation. Operator 2's incentives are unchanged: as in the base case (Section 5) it prefers to roam as long as the charge is lower than the cost of retaining coverage ( $\beta C_{NoRoa}$ ). However, Operator 1 cannot threaten to withdraw. This implies that, even if the roaming charge is so low (and incremental costs so high) that Operator 1 makes losses when offering roaming, it has no option other than continuing to cover the area. All Operator 1 can do is to reduce its investment and let the quality of its network deteriorate (Figure 5). In dual coverage areas a coverage obligation could, therefore, result in a worse outcome (in terms of likelihood to be able to make and receive calls) than without the coverage obligation.



**Figure 5: Incentives in dual coverage areas with a coverage obligation for Operator 1**



In summary, a coverage obligation eliminates the risk of turning a partial not-spot into a full not-spot. However, it still allows for a quality degradation in partial not-spots, which can be compensated for by the presence of two networks of low quality if the roaming charge is sufficiently high. In dual coverage areas, a coverage obligation for one operator makes it more likely to turn an area into a partial not-spot if the roaming charge is too low. The quality of the service may also be degraded.

## 7. Conclusions

The economic literature has examined the linkages between network investment and national roaming, though not to address partial not-spots. However, the existing contributions compare outcomes with and without national roaming, assuming that the regulatory regime is known before investment is sunk. Our approach differs in two main ways. First, we consider it is more realistic as it assumes that the policy is deployed after investment has already been sunk, and it is a first attempt to assess the impact of the policy on the scope and quality of coverage. Second, it is a very simple approach which offers practical advice to regulators on the level at which to set national roaming charges.

We have examined whether, as a result of a national roaming obligation, David would be more likely to make or receive a call from Angela when travelling across the UK. In order to illustrate the results of the analysis, suppose David subscribed to Operator 1. First, suppose David is in a partial not-spot area that is covered by Operator 1. In these areas, pre-national roaming obligation, David would have been able to make or receive a call. However, post national roaming obligation, this is no longer certain. If the roaming charge set by the regulator or government is set at the “wrong” level, Operator 1 may be better-off withdrawing its network, and David would no longer be able to make or receive calls. In some cases, David would still be able to speak to Angela, but the quality of the call may be worse (e.g. the signal may be less clear and/or a call drop may be more likely). Second, suppose instead David happened to be in a partial not-spot area that is covered only by Operator 2. David was not able to make and receive calls pre-national roaming obligation. He should be better-off if national roaming is introduced. However, the scope of this benefit depends on the incentives faced by Operator 2, which could cause it to withdraw its own network. These are similar to the incentives Operator 1 faces in the case discussed above. In the most likely case, David may be in a dual coverage area (covered by both Operator 1 Operator 2’s networks). Pre-roaming he was able to make calls; post

national roaming obligation, this may not always be the case. This is particularly so when both networks may end-up withdrawing their coverage. However, in other instances, David's Operator 1 network may become of worse quality and, hence, may result in a higher likelihood of disconnected calls and/or a lower quality signal.

**Table 5: David's ability to make and receive calls from Angela (David is on Operator 1 and there is no coverage obligation)**

	<b>Not-spot covered by Operator 1</b>	<b>Not-spot covered by Operator 2</b>	<b>Dual coverage area</b>
<b>Pre-roaming obligation</b>	Can make & receive calls	Cannot make & receive calls	Can make & receive calls
<b>Post-roaming obligation</b>			
Can make & receive calls with the same or higher quality if	$C_{Roa} + \Delta\pi_{Roa} < P_{Roa} < C_{Roll}$		$P_{Roa} > \beta C_{NoRoa}$ or $P_{Roa} < \beta C_{NoRoa}$ and $P_{Roa} < C_{Roa} - \pi_{NoRoa}$ (only if Operator 1 and Operator 2 cooperate)
Can make & receive calls with lower quality if	$C_{Roa} - \pi_{Roa} < P_{Roa} < C_{Roa} + \Delta\pi_{Roa}$ or, if Operator 1 and Operator 2 do not cooperate, $P_{Roa} > C_{Roll}$		$P_{Roa} < \beta C_{NoRoa}$ and $P_{Roa} < C_{Roa}$
Cannot make & receive calls if	$P_{Roa} < C_{Roa} - \pi_{Roa}$ or, if Operator 1 and Operator 2 cooperate, $P_{Roa} > C_{Roll}$		$P_{Roa} < \beta C_{NoRoa}$ and $P_{Roa} > C_{Roa}$ or $P_{Roa} < \beta C_{NoRoa}$ and $P_{Roa} < C_{Roa} - \pi_{NoRoa}$ (only if Operator 1 and Operator 2 do not cooperate)

Table 5 summarises the results for different levels of the national roaming charge. There is a substantial risk of regulatory errors in setting the roaming charge. It is possible that, under some circumstances, David may be less likely to be able to speak to Angela, which is the very opposite outcome of what a mandatory national roaming obligation aimed to achieve. This is compounded by the fact that the government, or the regulator, in practice will have to set a geographically uniform national charge, while profits will vary locally and over time. This could be partly mitigated by acting on the structure of the charge (i.e. adopting a non-linear charge structure). Lastly, we found that a coverage obligation in partial not-spots would reduce the risk of the area becoming a full not-spot, although it makes it more likely that the network service quality will deteriorate; in dual coverage areas, there is a substantially higher risk that when the roaming charge is low the area could become a partial not-spot, and that the quality of the remaining network deteriorate.

While national roaming as a tool to address concerns about not-spots was lively debated in the UK, this has not yet become a matter of regulatory concerns anywhere else. However, some of the effects we have examined in this article could also arise if national roaming obligation were adopted for a different purpose. There are two possible examples. First, Enisa (2013) noted that in 2012 79 significant outages accidents occurred across the European Union (EU), with on average 400,000 consumers losing access to mobile services each time. Enisa proposed national roaming as a way to ensure service continuity when major outages occur. This may have some, though perhaps small, effects on incentives to invest in dual coverage areas. Second, some MVNOs (e.g. 24 Seven in the UK) are launching services allowing their customers to roam on all national networks. Depending on the roaming charges this could also have an impact on the networks' incentives.

Our approach is very stylised in order to capture only one effect of a national roaming obligation. It could be extended in a number of ways. It could be turned into an equilibrium model, separately for partial not-spots and dual coverage areas, by assuming the policy is adopted after most of the investment is sunk. It could also be the basis for exploring the impact of a geographically uniform charge vs a more complex tariff when costs and demand are geographically heterogeneous. Lastly, in presence of limited sunk costs, networks could switch their coverage on and off, turning the game into one of repeated interaction.

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