

**Termination Charges for Mobile Phone Networks**  
**Competitive Analysis and Regulatory Options**

*by*

**Joshua S. Gans and Stephen P. King**  
**University of Melbourne**

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## **Executive Summary**

This paper presents new research into the determinants of prices and inter-network charges in relation to call termination. Our particular focus is the pricing of fixed to mobile calls and its interaction with competitive conditions in mobile communications.

We demonstrate that mobile termination service pricing and demand is substantially influenced by patterns of mobile competition, integration among different modes of telecommunication and consumer's difficulties in distinguishing among alternative mobile carriers when placing calls. These economic factors mean that market power is present and likely to be exercised in determining inter-network call charges to the detriment of end users and overall social value created.

Specifically, we find that:

1. Unregulated mobile termination charges will result in higher than monopoly call prices.
2. Mobile networks will negotiate low reciprocal termination charges so as to soften price competition.
3. The regulation of termination charges and prices downward will raise mobile subscription rates.
4. Regulation of any mobile carrier's termination charges can reduce fixed to mobile prices but will result in an increase in unregulated carriers' termination charges.
5. When fixed line consumers can distinguish between different mobile networks they are calling, fixed to mobile call prices will fall relative to their level under consumer ignorance.
6. Direct mobile charging for termination exerts downward pressure on the total fixed to mobile call price.
7. The issues in the setting of mobile originating charges for B-party paying calls involves the same issues and principles as those for termination charges.

We conclude that a low cost method of improving fixed to mobile outcomes would be to facilitate the identification of carriers by consumers and restructure billing so that mobile networks are able to directly charge fixed line consumers for termination services. These would provide conditions conducive to facilitating competition in termination services and hence, more efficient pricing outcomes among telecommunication networks. Nonetheless, such structural changes would be complimented by regulatory measures to ensure that termination charges were below the marginal cost of termination.

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# **1 Background<sup>1</sup>**

This paper is an economic investigation of the determinants of inter-network pricing in the context of mobile network competition. In particular, as part of general principles of interconnection or any-to-any connectivity, telecommunications carriers offer terminating services for calls originating off other networks. These services ensure that callers from other networks can reach those on a given telecommunication network and hence, are an essential ingredient in ensuring that telecommunications networks remain compatible. Given the convention that the caller pay the originating network directly, the terminating service involves the originating carrier paying the terminating carrier for that service. It is the determination of such inter-network (termination) charges that is the focus of this paper.

To be clear, a terminating service is essentially the carriage of a call from a point of interconnection between two networks to the consumer for whom the call is intended. Thus, the terminating network bears the trunk and connection costs from that point of interconnect to the consumer while the originating network bears the costs from the caller to the point of interconnect. Under the caller-pays principle of charging, however, the caller is charged for both the originating and terminating services. The originating network collects the call charge and that network and the terminating network must, in turn, transact for the terminating service. It is the price that the terminating network charges the originating one that is the focus of the present analysis. Not surprisingly, as that price becomes part of the marginal cost of the call service, it also an important factor in determining the overall price of the call.

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<sup>1</sup> We thank the Australian Competition and Consumer Commission (ACCC) for providing funds for this project. The views expressed are solely those of the authors and do not reflect those of the ACCC.

Our principal focus here is on termination charges that arise for calls made from fixed line to mobile networks. These termination charges are set by mobile networks while the ultimate price of fixed to mobile calls is set by the fixed line network. A regulatory concern arises because of a potential lack of competition on either end of this service. First, fixed line networks – particularly on the local loop – are still effective monopolies in many jurisdictions, including Australia. Hence, those networks are able to exercise considerable market power in the pricing of all their services.<sup>2</sup> Second, once a mobile network has attracted a consumer, it in effect owns the termination revenues that might flow to that consumer. This potentially gives it market power in the setting of termination charges for access to its consumers. In each of these cases, the ability of the fixed line or mobile carriers to exercise market power and create socially inefficient outcomes will depend on the possible substitute choices that are open to consumers of mobile and fixed services.

It is in this context that we conduct our analysis. In particular, we propose to examine two broad questions:

- What pricing outcomes for terminating services arise when telecommunications prices are not regulated?
- Where these outcomes differ from a socially optimal outcome, what is the effect of alternative regulatory rules on prices and competition?

In addressing the former question we will examine the unregulated outcomes in a context of fixed network monopoly and mobile network competition, including cases where some networks are integrated across alternative means of telecommunication. For the latter question we will examine a broad set of rules ranging from mandated negotiations to alternative billing patterns, the provision of greater levels of consumer information and the direct setting of termination charges. We will be concerned with questions such as: whether different carriers should receive different regulatory treatment based on

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<sup>2</sup> In Australia, these prices are now set by long distance carriers rather than the local network owner. Nonetheless, we will demonstrate below that this distinction is in many ways cosmetic.

relative market power? How closely should termination charges reflect termination costs? How changes in market structure and concentration include the rationale for regulation? And how changes in termination charges will alter the prices for other telecommunications services, including mobile network subscription charges.

The paper is organised as follows. In Section 2, we describe in more detail the economic forces that underlie the setting of termination charges and the reasons why regulation may be required. Section 3 then states and explains intuitively our modelling results concerning unregulated outcomes and the impact of alternative regulatory rules. Sections 4 and 5 provide a detailed technical analysis that underlay the results explained in section 3. Section 6 then considers the impact of fixed network competition while a final section concludes, identifying key directions for future research.

## **2 Economic Characteristics of Termination**

Before beginning the formal technical analysis, it is useful to summarise the economic factors that determine how firms will set mobile termination charges. There are five key characteristics of terminating services that drive their value and use. These are: (1) market power over access to a consumer; (2) consumer ignorance regarding the network called; (3) horizontal separation; (4) vertical separation; and (5) tariff-mediated network externalities.

### **2.1 Market Power Over Access to a Consumer**

Telecommunications involves a two-way network, where the party that makes and pays for the call is not always the same as the party that chooses which company will supply the call. This is the situation under mobile termination where the calling party, or the A-party to the call, pays the price of the call. Because of this, telecommunications companies tend to have some degree of market power when terminating calls. Once a person has decided to join a specific mobile network, that network has a degree of monopoly power over the price that it charges any other party wishing to call that specific person.

This market power may be trivial or non-existent in certain circumstances. For example, if a person choosing a mobile network cares as much about the price of incoming calls as they do for outgoing calls, then any attempt by a mobile network to raise its termination charges may lead such a person to change networks. This is likely to be approximately true where the mobile phone is to be used almost exclusively so that some family members can use fixed to mobile calls to contact other family members. The person

choosing the network will then tend to be equally concerned about incoming and outgoing call charges.

In general, however, it seems reasonable to assume that many parties choosing a mobile network attach a greater weight to the outgoing call charges that they pay directly than to the incoming call charges for which they, at best, are indirectly liable.

## **2.2 Consumer Ignorance Regarding Inter-Network Pricing**

The market power generated by the control of call termination might be relatively small except for a second characteristic of many telecommunications systems, including the current Australian mobile phone system. A person who calls a mobile phone user will often have little idea as to the exact mobile company that will terminate their call. In particular, unless the A-party remembers, when calling from the fixed network to a mobile network, which mobile phone companies happen to have which four digit prefixes, the A-party can only guess the exact mobile company that will terminate their call. For many fixed to mobile calls it seems reasonable to assume that the A-party has no information beyond the market shares of the mobile carriers or the probability that they might be calling one or other network. Such a customer will not know the cost of their call in advance but can only use an estimated price based on market shares.<sup>3</sup>

This effect is exacerbated in the context of number portability. Even where a prefix may have given some information regarding the network being called, with mobile number portability those differences will diminish in the future and make networks indistinguishable to the consumer.

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<sup>3</sup> In its inquiry into mobile termination, the UK Monopolies and Mergers Commission found that fixed line consumers had little knowledge of the mobile networks they were calling or of price differentials in carrier-specific call prices; see MMC (1998, pp.31-33).

To see the effect of this uncertainty, suppose that the opposite were true and a customer calling fixed-to-mobile both knows the identity of the terminating carrier and the price of the call. In some circumstances, the mobile network will retain some market power. If the A-party has to contact a specific person then they will still make the call, although if the per minute termination charge is high, they might truncate the call or ask the person on the mobile phone to call them back. In other cases, the mobile carrier will have little market power. If the A-party does not need to call a specific person, but rather can choose any individual from a group of people, then they will choose the individual who is cheapest to contact. For example, if the A-party needs to call a plumber, but has no preference over which plumber they contact, then they will choose the plumber that is linked to the mobile network with the lowest termination charges. This will, in turn, make the plumber indirectly face the termination costs – if they join a mobile network with high termination charges then they will receive fewer calls and less business. A mobile network with higher termination charges will have fewer members and competition will tend to moderate termination charges.

In contrast, suppose that the person making the fixed to mobile call is only able to guess at the identity of the terminating network. In particular, suppose that the A-party only knows the market shares of mobile carriers and can only estimate the average termination charge. Then each mobile network does not bear the full competitive consequences from raising their termination charges and, consequently, will have considerable discretion to raise these charges. When one network raises its termination charges, this raises the average price that the A-party pays. But the A-party only knows this average and because they cannot distinguish between mobile networks, they will make their calling decisions on the basis of this average, not the network specific charges. This, in turn, breaks the indirect link between termination charges and call frequency to a specific mobile customer.

Take the plumber example presented above. If the A-party cannot distinguish the identity of the terminating network before they make their call,

then this identity is irrelevant to the decision about which plumber to call. The person may call a plumber on a network with high or low termination charges, but they are only likely to know this when they receive a bill. This is too late for the A-party to change their calling decision. The plumber on a network that has high termination charges is no longer penalised through fewer calls for these charges, and so does not even indirectly bear these charges. In fact, to the degree that a network might pass some of these high termination charges back to a customer through lower prices for calls originating on the mobile network, the plumber might have an economic incentive to join a network with high termination charges.

We will refer to this effect, where a customer calling fixed to mobile cannot *ex ante* identify exactly which mobile network is associated with a particular mobile number, and so cannot identify the network that they are 'buying from,' as *customer ignorance*.

### **2.3 Horizontal Separation**

There are three further effects that exacerbate the concerns about termination charges. One of these flows from customer ignorance, and can be referred to as *horizontal separation*. As noted above, if a mobile carrier raises its termination charges under customer ignorance, this affects the average price that a customer pays for calling fixed to mobile. But it does not affect specific calls to any one mobile carrier relative to any other carrier because the customer cannot identify the carrier that they are calling. Thus, if one carrier raises its termination charges, and this raises the average fixed to mobile price, then customers may make fewer and shorter fixed to mobile calls. But they will make this adjustment for *all* such calls as they cannot identify the carrier they are calling. The network that raises its termination charges does not bear the full customer reaction from this price rise, but shares this reaction with the other mobile networks. In economic terms, there is a negative externality between mobile networks as each network is likely to receive fewer and

shorter fixed to mobile calls when another mobile network raises its termination charges. Basic economics shows how there will tend to be ‘overproduction’ of negative externalities. In this situation, the negative externality is associated with an increase in termination charges, so we would expect horizontal separation to result in excessive mobile termination charges.

## 2.4 Vertical Separation

Mobile termination charges are also likely to be inflated due to *vertical separation*. This effect is well known in economics.<sup>4</sup> If the fixed network and the mobile carrier are two separate companies, and these companies cannot bargain perfectly over non-linear termination charges, then the vertical separation will lead to ‘double marginalisation.’ The mobile carrier will tend to raise the price of termination above marginal cost so as to increase its own profits. But this raises the cost of mobile call termination as seen by the fixed network. To the degree that the fixed network has any market power, it will tend to set its fixed to mobile call prices by marking up this price over cost. However, the cost observed by this fixed carrier is not the true marginal cost of termination, but the higher termination price set by the mobile carrier. As a result, termination charges tend to be marked up over cost twice – once by the GSM carrier and once by the fixed carrier. In the extreme, this can lead to pricing above the vertically integrated monopoly price.

## 2.5 Tariff-Mediated Network Externalities

Finally, termination charges might not reflect competitive behaviour because of *network externalities* between mobile phone customers. These externalities exist if there are benefits to one consumer who buys a product when other consumers choose the same product. For example, when choosing

<sup>4</sup> See, for example, Perry (1989).

a computer operating system, a customer might be more willing to buy a particular system if a significant number of other consumers either have already bought this system or are likely to buy this system.

If mobile phone charges were cost reflective then it is not clear that there would be any network externality. But mobile carriers might have an incentive to use termination charges to create these externalities. For example, if a dominant mobile carrier wanted to stifle competition from a new entrant, it could set high call termination charges for that entrant. The dominant carrier's existing customers will be largely unaffected by these charges, but the new carrier's customers will face a high price when ringing the dominant mobile carrier. This can be a significant disincentive from joining the new carrier. There is a network externality because the high inter-carrier mobile-to-mobile charges make it cheaper for customers to ring each other if they all belong to the same network.

The anti-competitive effects that characterise termination charges are built into the models presented in this paper. For example, in section 4 we consider a model with exogenous mobile carrier customer shares that captures customer ignorance and both vertical and horizontal separation. This model allows us to focus on fixed to mobile termination charges and mobile-to-mobile termination charges. In section 5, this model is extended to allow for endogenous market shares. This allows us to focus on how termination charges can be used to attract customers to a particular mobile network and how they can be used to create network externalities. In each section, we consider different regulatory rules that might be imposed on the mobile carriers, and consider the effects of these rules.

## **2.6 Termination Charges and Access Pricing Issues**

Given the above, it is worth reflecting upon the difference between issues that arise from termination as opposed to those that arise when pricing access to essential facilities. Both share in common the idea that what is being

priced is an important input into a service. For termination, this is an input into an inter-network call service. For access, what is priced is an input into downstream production. However, it is the horizontal interactions highlighted above that distinguish termination issues from access issues.

To see this, recall that the issue in access is the leverage of monopoly power. That is, regulators are concerned that a firm with a monopoly or near monopoly in one part of the vertical chain of production might use that monopoly power to extend those monopolistic conditions and pricing downstream. Specifically, they might price in such a way that few firms are able to operate downstream. In this situation, the role of regulation is to facilitate downstream competition that might otherwise be harmed by discriminatory access pricing.

There is also a concern that termination charges could be used to either make entry difficult or raise rival's costs; thereby, harming competition in a related market. But in this case, the monopolistic conditions arise because of network effects. Termination services arise when networks interconnect with one another. As interconnection subdues the monopolistic tendencies of network effects while preserving their (demand-side) benefits, the issue of foreclosure is only salient when considering interconnection terms to 'smaller' players. Termination charges may be used in the same way as discriminatory access charges to raise rivals costs. On the one hand, this may lead to a reduction in network competition by making entry difficult. On the other, it may lead to a softening of price competition between established networks.<sup>5</sup>

But there is also the fact that there may simply be insufficient competition in certain inter-network services that is of concern to regulators when considering termination charges. That is, so long as there is customer ignorance, the termination service itself cannot be a locus of network competition. Indeed, because of this it can potentially be used as a means of

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<sup>5</sup> For a more extensive discussion of this point see Armstrong (1998).

cross-subsidising competition on main network services. Hence, the regulator is faced with difficult questions regarding the balance of prices among different network services, including termination services and cannot simply consider one without examining the consequences for others.

## **3 Key Results**

In this section we state our key results and the intuition behind them. The technical details are left to the next two sections. We will first consider the results regarding the pricing outcomes in an unregulated environment before considering the implications of alternative regulatory rules. Finally, we will comment on mobile originating charges for B-party payer calls and the role of fixed network competition.

### **3.1 Unregulated Outcomes**

#### **3.1.1 Fixed to Mobile Services**

As mentioned in the previous section, it is a basic fact of terminating services that the providers of such services have a certain degree of market power in setting terminating charges. Consider a mobile network with a given customer base. Even if that base is small, callers from other networks to those customers will have to pay a price for calls to that network that is in part influenced by the terminating charge set by that mobile network. But it is true that as the price of fixed to mobile calls rises, fewer such calls will be made. The elasticity of demand for fixed to mobile calls will, therefore, temper the market power of the mobile network. However, this effect is limited by customer ignorance. What this means is that if a given mobile network raises its termination charge this will influence the average number (or length) of fixed to mobile calls to all networks and will not cause that network to receive proportionately fewer calls than other mobile networks. This is because callers to mobile networks respond only to the overall price of fixed to mobile calls and cannot distinguish any price differentials in such calls to alternative mobile networks.

This gives us our first result:

**Result 1:** *Unregulated mobile termination charges will be higher than monopoly pricing of such services.*

This result is a combination of consumer ignorance, horizontal and vertical separation. To see this, suppose there was only one integrated provider of mobile and fixed line services. That network will base charges for its terminating service on the actual marginal cost of termination. As it has a monopoly, its fixed to mobile price will be a simple mark-up over those marginal costs resulting in a monopoly pricing outcome for such services.

If the networks were not vertically integrated, with the mobile network setting its termination charge independently then, when it can only set a uniform termination charge, it is likely to set that charge above its actual marginal termination cost. Otherwise it would not make a profit. The end result is what is referred to as ‘double marginalisation.’<sup>6</sup> As the mobile network raises the fixed network’s marginal cost of fixed to mobile calls, the price of those calls is higher. This results in lower consumption, reduced consumer surplus and also in lower profits for both networks than would arise under vertical integration. It is only when the two networks can negotiate non-linear termination charges (such as a two-part tariff) that the monopoly outcome will be restored with the termination charge set equal to actual marginal termination costs.

Horizontal separation of mobile networks combined with customer ignorance serves to exacerbate the double marginalisation effect; causing fixed to mobile prices to increase further. First, when consumers on the fixed network cannot easily determine the precise price of the mobile network they are calling, the fixed network can do no better than setting the same fixed to mobile call charge regardless of the network being called. This call price will be set on the average termination charges. Consequently, an increase in one mobile network’s termination charge will raise this average and the fixed to mobile price in general and not simply to its own network. Thus, an increase

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<sup>6</sup> For a discussion see King and Maddock (1996), Chapter 4.

in its termination charge has a negative external effect on the termination profits other mobile networks receive. Indeed, the smaller (in terms of market share) the mobile network, the less likely is it to internalise the demand-reducing effects of an increase in its termination charge. So the *less concentrated* the mobile network market, the higher will be the level of fixed to mobile call charges.

Indeed, this effect is strengthened further when mobile networks recognise the influence of termination profits on their own competitive interactions. When competing against each other, mobile networks will recognise that attracting a customer not only gives them revenues from the calls that the customer makes but also termination revenues from calls made to that customer. A mobile network with a higher termination charge will, therefore, receive more profits from a given customer without any reduction in calls to that customer; the calls to that customer are not influenced by the network they subscribe to because the caller cannot identify this network. So by having a higher termination charge, a mobile network effectively receives greater benefits from attracting a given customer and hence, can afford to offer more attractive subscription terms to that customer. All competing mobile networks will realise that relative charges from termination matter in raising their own overall profits and they will, consequently, raise their termination charges to increase these. It is possible that this interaction could go so far as to 'choke-off' fixed to mobile demand entirely. That is, termination charges may, in equilibrium, be so high that the fixed carrier is unable to profitably offer a fixed to mobile service.

One response to this may be for the fixed network to utilise its monopoly position to favour one mobile network. The favoured mobile network may receive a lower termination charge for calls made from its network to the fixed network. Its rival with higher charges would be in a diminished competitive position and hence, price competition among the networks would be weakened. This, in turn, would allow for a fixed to mobile service to have a lower price. In effect, a fixed and mobile network would be

getting together in a form of 'quasi-integration' to eliminate the negative externalities associated with customer ignorance and vertical separation. This, of course, would have a detrimental effect on the degree of mobile network competition.

The possibility of integration between the fixed network and one mobile network does not improve these outcomes. While such integration will reduce the average termination charge (as the integrated firm sets its implicit termination charge equal to marginal cost), this will cause the non-integrated mobile carriers to raise their termination charges accordingly. The end result is that the integrated carrier will receive a lower level of profits than if it was vertically separated. Hence, integration will not be advantageous. Only when integration leads to the ability to favour a single mobile network and soften price competition will such integration be profitable. This will reduce fixed to mobile prices but at the expense of a softening of price competition in the mobile market and the conferral of market power on the integrated carrier.

Finally, it is sometimes argued that mobile subscribers will have preferences for incoming as well as outgoing calls. Consequently, mobile networks may wish to utilise low fixed to mobile prices to attract consumers to their network and hence, lower their termination charges. However, so long as consumers on the fixed network are unable to distinguish between alternative mobile networks when making calls, their demand will be based on an average price. As such, mobile networks will be unable to utilise differences in termination charges to attract consumers to their network. So while a consumer preference for incoming calls may increase the attractiveness of subscribing to any mobile phone network; so long as there is customer ignorance, this will not exert any additional competitive pressure on termination charges.

### **3.1.2 Other Termination Services**

Mobile networks also offer a termination service for each other's mobile-to-mobile call traffic. The termination charges chosen here can directly

impact upon a rival's costs. In particular, an insistence on a high termination charge may make a rival uncompetitive. However, when two networks are not close substitutes, termination charges will not be effective as an entry deterrence device. Indeed, it is possible that such charges may become an instrument of collusion to raise each other's costs and soften price competition.<sup>7</sup>

However, mobile phone competition is often based on non-linear pricing (e.g., two-part tariffs) that make this type of collusion less likely. When networks can offer consumers a two-part tariff, they will optimally set all usage or per call charges equal to marginal cost; appropriating profit margins through fixed subscriber charges. For intra-network calls, these charges will reflect true marginal costs while, for inter-network calls, they will include the rival's termination charge. If rival networks choose their termination charges independently, they will select charges above their actual marginal termination costs. This is because they neglect the negative effect a higher price has on their rival's profits generating a similar outcome to the double marginalisation effect rather than a collusive choice per se. This gives each network an incentive to negotiate a reciprocal termination charge that equals marginal cost; thereby, nullifying the double marginalisation effect.

**Result 2:** *Mobile networks will negotiate low reciprocal termination charges so as to soften price competition.*

Mobile networks do not have an incentive to use high termination charges in order to facilitate collusion.

However, it is possible that networks could use low termination charges – the so-called 'bill and keep' rule – to soften price competition. That price competition takes place as networks lower subscription (or fixed) charges to attract customers. If attracting a customer also attracts lucrative termination revenues for calls to that customer, this only serves to raise the stakes of building market share. On the other hand, a reciprocal bill and keep

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<sup>7</sup> See Laffont, Rey and Tirole (1998a), Armstrong (1998) and Carter and Wright (1998).

rule means that an additional customer brings with it a liability – in the form of costs but no revenue from termination. Hence, the benefits the network can potentially derive from an additional customer are less and it will soften its price competition in response. In equilibrium, negotiating a bill and keep rule keeps network profits high by committing networks to termination losses; effectively raising each other's costs.

## **3.2 Regulatory Options**

The above analysis has indicated the mobile networks can potentially utilise termination charges in a way that softens price competition and, in the case of fixed to mobile calls, causes higher than monopoly prices for the overall service. These results suggest a role for regulation in curbing such potential abuse of market power. However, finding a regulatory option that fully resolves the concerns is difficult. Nonetheless, we have explored a number of regulatory options and were able to evaluate which ones were most likely to promote competitive and socially desirable ends.<sup>8</sup>

### **3.2.1 Mandated Negotiations**

As already alluded to above, negotiated outcomes on termination charges were often superior to more arms length, posted prices as they eliminated the negative externalities associated with double marginalisation. But, mandated negotiations also make it more likely that larger networks and fixed line networks with market power will be able to use discriminatory termination charges to weaken or deter entrants from effective interconnection.

However, even in the absence of entry deterrence, negotiated outcomes are not perfect. On fixed to mobile calls, the best negotiated outcome is

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<sup>8</sup> One option that we have not addressed is to provide mobile consumers with a 'receiver pays' option for fixed to mobile calls – as is practiced in the United States. Recent research suggests that this may have a beneficial effect on fixed to mobile prices and mobile competition. See Doyle and Smith (1998).

monopoly pricing of this service. On mobile-to-mobile calls, a negotiated outcome would lead to very low inter-network prices but at the cost of higher subscription charges. The low inter-network prices would be inefficient resulting in over-consumption of that service. These inefficiencies would be borne by subscribers to mobile networks; perhaps at the expense of mobile phone adoption. In this respect, while mandated negotiations are desirable in curbing the worst aspect of termination pricing they are unlikely to result in socially efficient outcomes.

### **3.2.2 Direct Regulation of Termination Charges and Prices**

A more direct means of controlling anti-competitive pricing of termination services would be regulating those prices. Of course, this would entail all of the practical difficulties associated with such regulation but ultimately there would likely be a reduction in such prices and a greater intensity of calls from fixed to mobile networks.

However, given the interdependencies identified earlier, a reduction in mobile termination charges for calls from fixed networks would impact on other prices. In particular,

***Result 3: Simple regulation of termination charges and prices downward will raise mobile subscription rates.***

Recall that, when termination charges are high, this means that mobile networks receive additional termination profits from attracting another customer. Such termination profits offset any costs associated with attracting a customer. Consequently, when those profits are high, this makes mobile carriers more set low prices to attract customers with any sacrifice in subscription revenues being made up for by additional termination profits. Consequently, if a regulated termination charge were to reduce termination profits, this will soften bidding and lower mobile network competition. This is because the lower termination charges mean that servicing marginal customers becomes effectively more costly for mobile networks and hence, their incentive to offer lower subscription rates is diminished. Thus, we expect that

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regulation of termination charges will lead to higher mobile subscription rates in the long-term than would arise in the absence of such regulation. Nonetheless, this could still be socially desirable as deadweight losses on the fixed to mobile service are reduced.

These considerations make benchmarking the appropriate termination charge difficult. What can be said is that an *upper limit* on termination charges should be the marginal cost of terminating a call on a mobile network. This is the appropriate benchmark that would arise if fixed carriers set fixed to mobile call prices in a competitive manner. Let us denote this by  $c_T$ . Given the possibility of congestion, this is likely to differ between peak and off-peak times. Nonetheless, it would be possible to use the lowest mobile call prices themselves to infer something about these costs. In particular, suppose that it was known that average trunk rates for mobile calls – say over long-distance lines – was  $c$  per minute. Thus, the total marginal cost of a call would be  $c + 2c_T$  (the latter term assuming that it costs the same to originate and terminate a call).<sup>9</sup> If, in a particular period, the *lowest* per call minute price of a mobile call was  $p$ , then *if this price is close to a competitive level*, a good approximation for  $c_T$  would be given by  $c_T = \frac{1}{2}(p - c)$ . Hence, the upper limit on termination charges for fixed to mobile calls should be  $\frac{1}{2}(p - c)$ .

Note, however, that it is important that this not be a formulaic regulated price in the sense that it would be updated based on observed call prices. This would give carriers an incentive to raise prices and may lead to a further softening of mobile network competition. Instead, the price could be based on current (pre-regulation) prices. Or, alternatively, the price used could be the minimum per call minute price of any mobile carrier. While not perfect, this would diminish the incentives of individual networks to raise call prices to strategically increase termination charges, as they would be the same across networks.

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<sup>9</sup> Some allowance would also have to be made for connection costs.

What is also true is that this possible termination charge represents an upper bound. The optimal charge would most likely involve a termination charge below marginal cost (i.e., below  $c_T$ ). This may involve a termination charge of zero; akin to a 'bill and keep' rule between fixed and mobile carriers. As noted above, the cost of this would be a potential increase in subscription rates. Nonetheless, going beyond a simple per call minute regulated charge could mitigate this.<sup>10</sup> If the fixed network were to pay mobile networks a fixed fee, this fee could be used to intensify mobile competition. This would involve rewarding networks that attracted subscribers with a higher fixed fee than those who lost subscribers. In effect, mobile networks whose customers churned to another network would be penalised with a lower fixed fee than those who attracted customers. Such use of a fixed fee could restore the competitive conditions in the mobile market while ensuring lower prices for fixed to mobile calls themselves.

What should be emphasised here is that regulated termination charges will have to be, in part, determined on a case-by-case basis. Individual networks will have different customer bases, coverage and asymmetric market shares. To the extent they use different technologies, they may also have different termination costs. These factors will have to be taken into account when determining how far below marginal cost termination charges should be set.

Finally, it is sometimes argued that regulation of the termination charges of dominant mobile networks (i.e., those with the greatest market share) would suffice to ensure more efficient pricing of fixed to mobile calls. To be sure, we find that regulation of the termination charge of dominant networks to marginal cost will lower such prices. However, the beneficial effects of such regulation are partly offset by an increase in the termination charges of unregulated carriers.

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<sup>10</sup> The logic here is similar to the use of fixed access charges proposed in Gans (1998).

**Result 4:** *Regulation of any mobile carrier's termination charges can reduce fixed to mobile prices but will result in an increase in unregulated carriers' termination charges.*

Thus, the reduction in fixed to mobile charges is not as great as it might be.

This suggests that there may be benefits to regulating all networks on similar terms. While regulating networks with the greatest market share will result in the largest reductions in fixed to mobile prices, this will make those networks less aggressive in maintaining their market share relative to those networks whose termination charges are not regulated. Hence, the regulated share will diminish relative to the unregulated share, raising average termination charges and hence, fixed to mobile prices. The longer there is asymmetry in regulation among networks, the longer are potential losses in competitive neutrality among them likely to persist. In the short-term, this may assist entry. However, in the long-term this could lead to inefficient pricing outcomes.<sup>11</sup>

### **3.2.3 Carrier Identification**

A critical reason for high fixed to mobile call prices is the inability of fixed-line customers to distinguish between alternative mobile networks they are calling. This means that price differentials among networks – in particular, driven by potentially different termination charges – do not cause asymmetries in calling patterns and termination profits to each. Thus, competition among mobile networks for termination revenues is muted.

This suggests that providing a means of carrier identification to consumers could break this competitive barrier. Specifically, we find that when consumers can distinguish between networks, termination charges are reduced; although they still result in call prices above monopoly levels due to the effect of double marginalisation.

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<sup>11</sup> The issue of the regulation of termination charges for non-dominant networks is dealt with extensively in Gans and King (1999).

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**Result 5:** *When fixed line consumers can distinguish between different mobile networks they are calling, fixed to mobile call prices will fall relative to their level under consumer ignorance.*

Carrier identification removes the externalities associated with horizontal separation and makes possible termination charges closer to marginal cost. Indeed, when the fixed and mobile networks negotiate, they would try to agree to charges equal to marginal cost and the resulting call price would fall to a monopoly level.

Providing consumers with information regarding call prefixes would facilitate such identification in the short-term. But this form of network identification would weaken overtime with the introduction and spread of mobile number portability. Alternatively, perhaps a distinctive sound may be played when a call is places to a particular mobile carrier. Finally, greater advertising and awareness of any termination and fixed to mobile price differentials could encourage consumers to be aware of the carriers friends, family and work colleagues subscribe to. These things would assist in making termination services more competitive.

### **3.2.4 Direct Termination Charging**

Termination charges are more difficult to change (particularly if they are negotiated) than the actual price of fixed to mobile calls. Laws preventing resale price maintenance and also the need to have information regarding costs reinforce this. This pre-commitment is a source of power for mobile networks who can effectively act as price leaders in the setting of fixed to mobile call prices to end users. This suggests that a minimal regulatory change that might improve competitive outcomes would be for mobile carriers to directly set the price of termination to fixed line callers. That is, a fixed line bill would be comprised of two components; a terminating charge and a trunk-originating charge. The actual billing would still be done by the fixed carrier (in return for a regulated billing fee) and calls would still be paid for by the caller. However, the mobile network would directly – rather than indirectly – determine the

termination charge. It will not alleviate consumer ignorance but perhaps it could also be used to facilitate learning in this regard.

Under direct charging, some of the negative effects of vertical separation are removed.

**Result 6:** *Direct mobile charging for termination exerts downward pressure on the total fixed to mobile call price.*

To be sure, because terminating and originating services are complements, there will be some double marginalisation effect. However, it will not be as severe and hence, the total price of a fixed to mobile call is likely to fall.

### 3.3 Mobile Origination Charges

Origination charges are relevant for services such as 1-800 numbers, where the B-party pays for the call. If mobile operators have fixed market shares, then these origination charges raise similar issues to termination charges. B-parties receive calls from mobiles in a ratio that (approximately) equals the market share of the mobile carrier. But each B-party does not decide on the volume of calls that it receives and, for many services, may have only a relatively slight control over the length of the call. Thus, the critical margin of choice for the B-party is whether or not to offer the service at all.

Suppose that the demand curve for 1-800 and similar services is downward sloping. If origination charges are higher, then fewer B-parties will take up the service. Also, assume that the B-party cannot select which mobile carriers can be used to call its number. Then exactly the same issues as arise in fixed-to-mobile termination charges arise for origination charges. In particular, from the B-party's perspective there is consumer ignorance in the sense that they simply receive a sample of calls from all mobile carriers and the weight of calls in the sample is (approximately) the same as the market shares of each carrier. Each mobile carrier has an incentive to overprice origination charges and these charges will be above the monopoly price whenever there is mobile carrier competition.

One regulatory solution to this problem of customer ignorance and horizontal separation is to allow the B-party to choose which mobile carriers can use its service. In other words, rather than being a service that is available for all mobile carriers' customers, 1-800 and similar services would only be available if the B-party and the mobile carrier reached an agreement. Note that for originating charges, selectivity of mobile carriers is equivalent to mobile carrier identification for termination charges. The effectiveness of this solution will depend on the ability of the carrier and B-party to agree on non-linear prices and the potential for double marginalisation when a fixed carrier lies between the mobile carrier and the B-party and can strategically set the trunk and termination charge for the mobile carrier. If there are no constraints on the ability of the mobile carrier and the B-party to choose non-linear pricing and there is, say, a regulated carriage and termination charge for the fixed carrier, then individual mobile carrier negotiation and choice is likely to be relatively effective. The agreed originating charges are likely to be relatively efficient and the marginal charge will reflect marginal cost.

Alternatively, the regulator might choose a more intrusive form of regulation, such as directly setting the origination charges. This is most likely to be a relevant solution if it is impossible for the B-party to selectively make a 1-800 or similar service available to mobile carrier customers.

The situation is more complex if there is competition between mobile companies for customers. Termination charges for 1-800 and similar services are a form of extra revenue that is attached to winning a customer. Strategically, they are identical to the termination charges set by the mobile carriers for fixed-to-mobile calls. In the absence of agreement between mobile carriers, these charges will tend to be set above cost and this will lead to increased competition for mobile customers. If the mobile carriers can mutually agree to set these charges then they will want to agree to set them to a low level to mute price competition.

Again, if origination charges are set excessively high (such as the choke price) then either mobile carrier selection or more intrusive direct regulation can be used.

### **3.4 The Role of Fixed Network Competition**

Our analysis above has taken place in the context where there was a monopoly or dominant fixed network, or alternatively, where fixed networks had a large degree of market power. Thus, it is sometimes argued that if there were competition among fixed networks this would assist in reducing fixed to mobile charges.

Fixed network competition will certainly reduce the margins those networks charge on fixed to mobile calls. However, these margins are above marginal costs that are based, in part, on the termination charges set by mobile networks. The incentives of those networks to keep those charges high remain even when there is fixed network competition. This is because consumers are still ignorant of the mobile network they are calling. Consequently, encouraging competition among fixed network does not reduce the case for introducing the suggested regulatory alternatives above.

An alternative that is currently being pursued in Australia is to allow customers to pre-select a carrier that will bill them for fixed to mobile calls. In the absence of any further regulation, this pre-selection will be analogous to direct charging by mobile carriers. The pre-selected firm will negotiate directly with the fixed and mobile carriers regarding the charges for fixed to mobile calls. If there is strong competition between pre-selected firms, then the negotiated charges will be passed on directly to the end users.

The use of pre-selection for fixed to mobile billing does not remove the issues of horizontal or vertical separation and, by itself, makes no change to the problem of customer ignorance. The pre-selected firm is simply an agent for the individual consumers. But as noted above, direct charging by mobile

carriers does change the strategic interaction between firms and can reduce fixed to mobile charges. Mobile pre-selection will also have this effect.

To the degree that there is extra regulation with pre-selection, the price of fixed to mobile charges will alter. For example, suppose that the fixed carrier is not regulated with regards to the price it can set for fixed to mobile calls, but that the charge for fixed line origination under pre-selection is regulated at a price below the profit maximising price for the fixed carrier. Then pre-selection will pass this lower price onto the customer. The lower fixed network origination charge will result in lower overall fixed to mobile prices. This will be at least partially offset by the mobile carriers raising their termination charges. Overall, the customers and the mobile carriers will gain at the expense of the fixed carrier. While this might appear to be a benefit of pre-selection, the same result could be achieved with direct mobile charging where the fixed carrier faces the same regulation as under pre-selection.

### **3.5 Conclusion**

Each of the above regulatory options, at best, would restore fixed to mobile prices to their monopoly level. A possible exception is the direct regulation of that price. However, such regulation may result in an increase in other mobile prices.

Nonetheless, our analysis has suggested that a key component to more efficient outcomes in termination services is changes that facilitate the introduction of competition there. In particular, a combination of carrier identification and direct mobile charging would comprise a minimal regulatory means that may have a large effect on fixed to mobile prices. Carrier identification would make competition for termination revenues possible and allow mobile networks to satisfy consumer preferences for incoming calls to their mobiles in order to gain a competitive edge. Direct mobile charging would strengthen this by giving mobile networks a more direct link with the total price of fixed line calls to their network. These

changes would break up the current conditions that serve to stifle competition for termination services.

## 4 Exogenous Mobile Network Market Shares

In this section and the next we provide a detailed, technical analysis of the results and conclusions discussed above. We divide our analysis into two parts. First, we focus exclusively on the determination of fixed to mobile call charges in a context where mobile networks' market shares are exogenous. On one level, this is a device to simplify the strategic interactions that might otherwise emerge and isolate some important effects in the determination of fixed to mobile call charges. On another level, the fixed market share case may be applicable to situations where mobile networks are not strong substitutes. In particular, the two networks may cover different regions or consumer groups. Nonetheless, the exogenous market share case does hold constant other prices of relevance in mobile competition. Consequently, in section 5, we develop a model of mobile network competition to explore the interactions between fixed to mobile prices and other prices that may be set by fixed and mobile carriers. We will see that the logic of many of the results presented in this section continues to be valid even in the more complex framework developed later on.

### 4.1 Model Set-Up and Assumptions

Consider a model with  $n$  mobile networks each owned by a separate firm, and a single fixed network. Mobile phone customers are distributed between the various mobile networks where  $s_i$  is the market share of mobile network  $i$ . The marginal cost of terminating a call on a mobile network is given by  $c_T^M$  while the marginal cost of originating a call on the fixed network is  $c_O^F$ . The marginal cost of trunk services is given by  $c_1$  so that the total marginal cost of a fixed-to-mobile call is given by  $c_{FM} = c_O^F + c_1 + c_T^M$ .

We begin by considering the termination charges that will be set for fixed-to-mobile calls by the mobile carriers. We will see below that the same type of issues arise for termination charges between mobile networks and for originating call charges to ‘B-party pays’ services under the fixed market shares assumption.

Let  $P_i$  be the price of a call from the fixed network to mobile network  $i$ . We can think of this price as either being a price per call or a price per minute of the call. The fixed carrier will set the price. In this section, we assume that either (1) the fixed carrier is unable to set a different price for different mobile networks, so that  $P_i = P_j = P$  for all mobile carriers or (2) that the customers cannot determine which mobile carrier they are ringing *ex ante*. Under this later assumption, the fixed carrier could set different prices for different mobile carriers but these prices would only influence consumers’ decisions to the extent that they change the average price,  $P$  that customers pay. This average price determines demand and is given by  $P = \sum_i s_i P_i$ . The second assumption captures the idea of consumer ignorance discussed above.

As consumers either explicitly or effectively face a single (average) fixed-to-mobile price,  $P$ , the demand for fixed-to-mobile calls is given by  $Q(P)$ . It is often convenient to assume that this demand is linear so that  $Q = \frac{1}{2b}(a - P)$ . The linear demand assumption allows us to explicitly calculate prices and charges and to compare these charges over different regimes. The fixed carrier will set the price of fixed-to-mobile calls taking into account both the demand for such calls and the cost of those calls.

If the fixed and mobile networks are owned by separate firms, then the marginal termination cost that will enter the fixed carrier’s pricing policy is not the true marginal cost of termination,  $c_T^M$  but rather the marginal termination charge set by the mobile carrier. We denote the marginal termination charge set by mobile carrier  $i$  by  $T_i$  per call.

A useful benchmark price for our analysis is the uniform monopoly price for fixed-to-mobile calls. This is the profit maximising price that would be set by a single firm that owned both the fixed network and the only mobile network. We denote this price by  $P^m$ , where this price is implicitly defined for a general demand function by  $Q'(P^m)(P - c_{FM}) + Q(P^m) = 0$ . For the case of a linear demand,  $P^m = \frac{1}{2}(a + c_{FM})$  and the associated monopoly quantity is  $Q^m = \frac{1}{4b}(a - c_{FM})$ . Monopoly profits from the sale of fixed-to-mobile call services in this situation is denoted by  $\Pi^m = \frac{1}{8b}(a - c_{FM})^2$

## 4.2 Unregulated Outcomes Without Integration

Suppose that the  $n$  mobile networks independently and simultaneously set their linear termination charges  $T_i$ . The fixed network owner then sets the fixed-to-mobile price  $P$ . Given this (average) price, customers decide how many fixed-to-mobile calls they will make, taking into account their own ignorance of the identity of the terminating mobile carrier for any specific call. With each decision, the relevant firm seeks to maximise its profits and all networks take the market shares of each mobile carrier as given. Given the termination charges, the fixed carrier will set  $P$  to solve:

$$\max_P \left( P - c_O^F - c_1 - \sum_i s_i T_i \right) Q(P)$$

The solution to this problem is given by  $P = \frac{1}{2}(a + \sum_i s_i T_i + c_O^F + c_1)$  with associated quantity  $Q = \frac{1}{4b}(a - \sum_i s_i T_i - c_O^F - c_1)$ . Given the behaviour of the fixed carrier, the mobile networks will simultaneously set their termination charges to solve:

$$\max_{T_i} \frac{s_i}{4b} (T_i - c_T^M) (a - \sum_j s_j T_j - c_O^F - c_1)$$

The first order condition for the mobile carriers optimisation problem is given by:

$$a - \sum_{j \neq i} s_j T_j - 2s_i T_i - c_O^F - c_1 + s_i c_T^M = 0$$

Solving these first order conditions simultaneously for all mobile carriers gives the Nash equilibrium termination charges.

There are three cases worth more detailed consideration. First, suppose that there is just one mobile carrier. This allows us to capture the effect of double marginalisation by itself. In this situation,  $s_i = 1$ , so that  $T = \frac{1}{2}(a - c_O^F - c_1 + c_T^M)$  and  $P = \frac{1}{4}(3a + c_{FM}) > P^m$  so long as  $a > c_{FM}$ . The total quantity of fixed to mobile calls is given by  $Q = \frac{1}{8b}(a - c_{FM})$ . This is the standard *double marginalisation* result. The vertical separation of the fixed and mobile carriers leads to pricing above the monopoly level. This is detrimental for both consumers and for the firms themselves. The monopoly price maximises industry profits so that a higher price under vertical separation actually leads to lower industry profits than an integrated monopoly. In this situation, the mobile carrier's profits are  $\frac{1}{16b}(a - c_{FM})^2$  while the fixed carrier's profits are  $\frac{1}{32b}(a - c_{FM})^2$ . In total, these profits equal  $\frac{3}{32}(a - c_{FM})^2$ , less than the profits for an integrated monopoly given above.

Second, suppose that there are only two mobile networks. Solving the first order conditions for these two networks gives the termination charges as  $T_i = \frac{1}{3s_i}(a - c_O^F - c_1 + (2s_i - s_j)c_T^M)$  for each of the two mobile carriers  $i$ . The (average) price of fixed to mobile calls is given by  $P = \frac{1}{6}(5a + c_{FM}) > P^m$  with associated quantity  $Q = \frac{1}{12b}(a - c_{FM})$ . Note that in this situation that the price of fixed to mobile calls is higher than in the case of a single mobile carrier. This is due to the effect of horizontal separation. Each network has an incentive to unilaterally raise its termination charge relative to the case of a single carrier as it gains the full price benefit of such a rise but shares any related loss in sales. This effect tends to be larger for small networks. Note that as the market share of any mobile carrier decreases, its (equilibrium) termination charge increases. In particular,

$$\frac{\partial T_i}{\partial s_i} = -\frac{1}{3s_i^2}(a - c_{FM}) < 0.$$

At the same time, the share of the other carrier must increase and its termination charge falls. In the linear demand case considered here, the changes in termination charges that result from changes in mobile carrier market shares exactly offset each other. In other words, for the case of two mobile carriers, the price of fixed to mobile calls is independent of the shares of the individual mobile carriers even though the specific termination charges do depend on these shares.

The third case of interest allows for competition between an arbitrary number of symmetric mobile carriers. From the first order conditions, with  $n$  mobile carriers, each of whom has a market share of  $1/n$ , each carrier will independently set its termination charge in equilibrium at  $T_i = \frac{n}{n+1}(a - c_O - \zeta + \frac{1}{n}c_T^M)$ . The price of fixed to mobile calls is  $P = \frac{1}{2(n+1)}((2n+1)a + c_{FM})$ . We can see that this price increases as the number of mobile carriers increase. Differentiating the fixed to mobile price with regards to  $n$  gives:

$$\frac{dP}{dn} = \frac{1}{2(n+1)^2}(a + c_{FM}) > 0.$$

In other words, the price of fixed to mobile calls increases as the number of mobile carriers increases. This reflects that, in terms of fixed to mobile calls, there is not really any competition between mobile carriers. Because the person making the call is ignorant of the specific carrier they are calling, mobile carriers have no incentive to compete by offering a lower termination price. But as the number of carriers increases, the effect of horizontal separation rises and this pushes up the termination charges and the fixed to mobile price.

### 4.3 Regulation

What effect does different types of regulation of termination charges have when there is no integration between the fixed carrier and any mobile carrier? There are clearly a variety of rules that can be applied. We begin by considering the simplest possible rules, noting as we progress the limitations of the rules.

#### 4.3.1 Bargaining between the fixed and all mobile carriers

This minimal rule simply requires bargaining between the carriers to determine termination charges. If this bargaining is efficient, then it will internalise the effects of horizontal and vertical separation. This follows by definition. Efficient bargaining between the carriers will maximise the joint profits of the carriers and this involves establishing a monopoly price  $P = P^m$  for fixed to mobile calls. In order to achieve such a price, the mobile carriers would need to agree to set termination charges at marginal cost. In other words, the marginal termination price would be  $T_i = c_T^M$ . Profits would be shared by the mobile and fixed carriers through the use of 'up front fees' or equivalent lump-sum transfer payments.

If bargaining is efficient then the outcome will be equivalent to an integrated monopoly. If bargaining is inefficient then the result is more likely to resemble the even greater overpricing shown above. Even so, the efficient bargaining outcome does provide insight into the nature of efficient termination charges. In particular, these are likely to be non-linear charges such as two-part tariffs. It is likely to be socially desirable for the regulator to encourage such two-part tariffs, particularly as part of a bargaining process between carriers.

#### 4.3.2 Direct mobile charging

An alternative, minimal regulatory rule could involve the mobile carriers directly charging the A-party for call termination. In other words, the

fixed carrier would only charge a customer the origination and trunk fee for a fixed-to-mobile call while the mobile carrier would charge the customer the termination charge. To make such a rule feasible, the actual billing would have to be done by the fixed carrier, possibly in return for a regulated billing fee.

Having direct mobile charging would not effect of customer ignorance. A customer would still not know which mobile network was associated with a specific number until after they had been billed. But it would alter the strategic interaction between the fixed and the mobile carriers. In particular, it will help to offset the effects of vertical separation.

To see the effects of direct mobile charging, suppose that the fixed network sets a price for origination and trunk carriage of  $O$ . The total price for a call from the fixed network to the mobile carrier  $P_i = O + T_i$ . Under customer ignorance, with the shares of each mobile company given by  $s_i$ , the expected price that the customer pays for a fixed to mobile call is  $P = O + \sum_i s_i T_i$ . The fixed carrier and mobile carriers simultaneously set their charges so that the fixed carrier solves:

$$\max_O \frac{1}{2b} (a - O - \sum_i s_i T_i) (O - c_O^F - c_1).$$

The first order condition for the fixed carrier is given by  $a - 2O - \sum_i s_i T_i + c_O^F + c_1 = 0$ . Each mobile carrier will solve:

$$\max_{T_i} \frac{s_i}{2b} (a - O - \sum_i s_i T_i) (T_i - c_T^M).$$

The first order condition for each mobile carrier is  $a - O - 2s_i T_i - \sum_{j \neq i} s_j T_j + s_i c_T^M = 0$ . Again, it is worth looking at three cases – a single mobile carrier, two mobile carriers with asymmetric market shares and  $n$  symmetric mobile carriers.

First, if there is a single mobile carrier, solving the first order conditions gives  $O = \frac{1}{3}(a - c_T^M + 2c_O^F + 2c_1)$  and  $T = \frac{1}{3}(a - c_O^F - c_1 + 2c_T^M)$ . The total price of a fixed to mobile call is given by  $P = \frac{1}{3}(2a + c_{FM})$ . Note that this

price is below the standard double marginalisation price, which reflects that the direct mobile charging is reducing the effect of vertical separation. At the same time, direct mobile charging introduces a new element of horizontal separation. The fixed and mobile components of the call are now complementary inputs from the consumers' perspective, but are provided by different firms. Thus, the mobile direct charging does not completely internalise adverse spillovers in firm pricing and still leads to a price above the integrated monopoly price.

Second, we can consider that there are two mobile carriers with potentially different market shares. In this situation, solving the first order conditions gives:

$$O = \frac{1}{4}(a + 3c_O^F + 3c_1 - c_T^M) \text{ and } T_i = \frac{1}{4s_i}(a + c_T^M(3s_i - s_j) - (c_O^F + c_1)).$$

This gives an expected total price  $P = \frac{1}{4}(3a + c_{FM})$ . As with the unregulated case, the total price of a fixed to mobile call is independent of the actual shares of the mobile carriers in the case of linear demand. But the price is lower with direct mobile charging than with standard vertical separation. The specific termination charges set by each carrier will depend on their market shares and, as in the case without regulation, these termination charges tend to rise for a carrier as its market share falls.

Third, we can consider the  $n$  symmetric mobile carriers. Solving the first order conditions in this situation gives a total price of  $P = \frac{1}{n+2}((n+1)a + c_{FM})$ . To see the effect of increasing the number of mobile carriers with direct charging,

$$\frac{dP}{dn} = \frac{a - c_{FM}}{(n+2)^2} > 0.$$

The price of fixed to mobile calls rises as the number of mobile carriers increases even with direct charging.

Overall, direct mobile charging, even in the presence of customer ignorance, tends to result in lower fixed to mobile prices than no regulation.

But at the same time, it still leads to prices above the integrated monopoly level, and the price tends to rise as the number of mobile carriers increases.

### 4.3.3 Carrier identification

An alternative regulatory approach would involve carrier identification. At a minimum, this would involve advertising which carriers were associated with which numbers to reduce customer ignorance. Even so, this would only be a short-term solution and would not be amenable to mobile number portability. Carrier identification could involve a customer being informed of the identity of the mobile carrier that they are calling after they dial the number but before billing commenced. A simple sound may suffice.<sup>12</sup> The customer would then have the option of terminating the call if they did not want to buy the relevant call.

If caller identification perfectly removes customer ignorance then each mobile carrier is independent and there is no horizontal spillover between carriers. If there is no customer substitution then the fixed carrier and each mobile carrier are, in effect, a separate vertical pair. In other words, if a customer wishes to call a person or company connected to a specific mobile carrier and there is no alternative to this call, then the fixed and relevant mobile carriers are just like sequential monopolists. As a result, the behaviour of the fixed carrier and each mobile carrier will be identical to the case analysed above for a single mobile carrier. In other words, for each mobile carrier,  $T = \frac{1}{2}(a - c_O^F - c_1 + c_T^M)$ ,  $P = \frac{1}{4}(3a + c_{FM}) > P^m$  and  $Q = \frac{s_i}{8b}(a - c_{FM})$ . Each fixed to mobile call will have an identical price if each mobile carrier has an identical cost structure. The prices will not depend on the market share of each carrier in the case of linear demand. In this situation, carrier identification completely removes the effect of horizontal separation but it has no effect on vertical separation.

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<sup>12</sup> 'AT&T' have a simple identification sound in the US.

Alternatively, suppose that there is customer substitution between carriers. This will tend to reduce the ability of each mobile carrier to exert any monopoly power. We would expect mobile termination charges to fall and this to be reflected in the fixed-to-mobile price. In the extreme, suppose that there is perfect substitution between mobile carriers. In this case, a customer has numerous firms or people that they could call, and these firms or people are connected to different networks. The customer does not care which firm or person they call and will simply choose the firm or person associated with the cheapest fixed-to-mobile price. This leads to perfect competition between the mobile carriers, and termination charges will be set at marginal cost. The fixed carrier, however, retains all of their monopoly power and can set the price of fixed-to-mobile calls equal to the monopoly price.

#### 4.3.4 Carrier identification and direct mobile charging

It might seem sensible to use direct mobile charging to reduce the effect of vertical separation and carrier identification to remove the effect of horizontal separation. First consider the case with no customer substitution between mobile networks. If these regulatory options are both implemented, then the result for the fixed network and each individual carrier will be like the situation of direct mobile charging with only one mobile carrier. In other words, for each mobile carrier,  $O = \frac{1}{3}(a - c_T^M + 2c_O^F + 2c_1)$  and  $T = \frac{1}{3}(a - c_O^F - c_1 + 2c_T^M)$ . The total price of a fixed to mobile call is given by  $P = \frac{1}{3}(2a + c_{FM})$ . Again it is worth pointing out that this price is below the price established with just carrier identification, but remains above the integrated monopoly price.

As substitution between mobile carriers increases, termination charges under direct mobile charging will decrease until, with perfect substitution, the charges equal marginal cost. Again, the fixed carrier retains its monopoly power so that the origination charge will be set at the monopoly level,  $O = P^m - c_T^M$ .

### 4.3.5 Direct setting of termination charges

One obvious regulatory option is to allow the regulator to set termination charges directly. Suppose the regulator establishes a termination charge  $t$  that must be set by all mobile carriers. The fixed carrier will then take this regulated charge as given and set the price of fixed to mobile calls to maximise profits. As the termination charges are now simply a cost to the fixed carrier, and all strategic interaction is removed, the profit maximising price of fixed to mobile calls will be  $P = \frac{1}{2}(a + c_O^F + c_1 + t)$ . If we compare this with the integrated monopoly then  $P - P^m = \frac{1}{2}(t - c_T^M)$ . If the regulator sets the marginal termination charge equal to the marginal cost of termination, then the price will equal the integrated monopoly price. If the regulator sets a termination charge above marginal cost then the fixed-to-mobile price rises, while if the regulator sets a termination charge below the marginal termination cost, then the fixed-to-mobile price falls below the monopoly price.

The socially optimal price for fixed-to-mobile calls is given by the marginal cost of these calls,  $c_{FM}$ . The regulator would have to set the termination charge at  $t^* = c_O^F + c_1 + 2c_T^M - a$  before profit maximisation by the fixed carrier was aligned with the social optimum.

For any higher termination charge,  $t > t^*$ , the social welfare will be decreasing as the termination charge rises. In particular, note that it is not optimal for the regulator to set the termination charge equal to the marginal cost of termination. This only leads to integrated monopoly pricing and monopoly profits for the fixed carrier. Rather, to raise social welfare the regulator needs to set the termination charge below marginal cost. This creates a problem for the regulator. The mobile carriers will make a loss on terminating calls. This loss will need to be recouped from some other source. For example, if the regulator set the termination charge below cost, but that is all, then the mobile carriers would have to recoup their losses from terminating calls by raising charges on outgoing calls. If competition prevented this, then some carriers would need to leave the industry to reduce competition and

allow prices to rise. In brief, setting the termination charges below cost to correct the distortion in fixed to mobile calls will lead to a reduction in mobile competition.

An alternative for the regulator would be to set the termination charge below cost and then to require that the fixed carrier pay a lump-sum fee to each of the mobile carriers. The fixed carrier makes substantial profits on fixed to mobile calls under regulated termination prices and so long as the regulated termination price is not set below  $t^*$  then the profits of the fixed carrier will always be more than adequate to compensate for the mobile carriers' losses.

The problem with this alternative is the setting of the fixed fee. Note that this fee cannot be based on the number of calls or it effectively becomes a marginal or per call charge. If the fixed fee is set on the basis of call numbers (even, say, delayed by twelve months) then much of the advantage of setting a low termination charge will be lost.

There are two obvious alternatives that can be considered in more depth. First, the regulator can set the termination charges equal to marginal cost. As noted above this will lead, at best, to the integrated monopoly price for fixed to mobile calls. However, this assumes that the regulator can correctly and accurately identify the marginal termination cost. If the regulator is uncertain about this cost, and must rely on information from the mobile carriers themselves to determine this cost, then the mobile carriers have an incentive to overstate termination charges. If there is just a single mobile carrier, then this leads to a standard adverse selection problem in regulation.<sup>13</sup> The regulator's reliance on the mobile carrier for information in this situation would lead to termination charges that almost always exceed cost and prices for fixed-to-mobile calls above the integrated monopoly price.

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<sup>13</sup> See, for example, Baron and Myerson (1982) and Baron (1989).

If there are multiple mobile carriers but the regulator is uncertain of the true termination cost, or if the regulator has access to cost information from mobile carriers in a different country, then the regulator can use yard-stick comparisons to help set the termination fees.

Alternatively, the regulator could set termination charges at zero. This rule has the benefit that such termination charges will help offset the monopoly pricing by the fixed carrier. Further, if  $a$  is large relative to  $c_{FM}$ , then a zero termination charge can still exceed  $t^*$ . But if  $a$  is relatively close to  $c_{FM}$  or  $c_T^M$  is relatively large, then zero termination charges may be below the socially optimal level.

Zero termination charges have an additional advantage that they are easy to implement. The regulator simply does not allow mobile carriers to charge for termination. As the fixed carrier actually bills the customer, this carrier can enforce the rule by simply not passing any fees onto the mobile carriers. At the same time, zero termination fees will result in the mobile carriers making a loss from terminating fixed-to-mobile calls. To avoid these losses from impacting on other aspects of mobile phone competition, the mobile carriers will need to be compensated for this loss, say by a fixed per carrier transfer from the owner of the fixed network.

#### 4.3.6 Intervention for only a dominant carrier

An alternative to direct price setting for all mobile carrier termination charges would be to just set the termination charge for a 'dominant' carrier. To see the effect of such a policy, suppose that there are  $n$  mobile carriers, and they have asymmetric market shares. Let  $s_j > s_i$  for all firms  $i \neq j$  so that firm  $j$  is the 'dominant' carrier. The regulator directly sets its termination charge for fixed-to-mobile calls at  $t$ . All other carriers then simultaneously set their termination charges. Given these termination charges, the fixed carrier sets the price for fixed-to-mobile calls.

Using the first order conditions presented in section 2.1 above, replacing  $T_j$  with  $\mathbf{t}$ , we see that mobile carrier  $i$  will set its termination charge so that

$$a - \sum_{k \neq j} s_k T_k - s_j \mathbf{t} - 2s_i T_i - c_O^F - c_1 + s_i c_T^M = 0.$$

To simplify, assume that all non-dominant (and non-regulated) mobile carriers are symmetric with market shares  $s_i = \frac{1}{n-1}(1-s_j)$ . From the first order condition for profit maximisation for each non-regulated mobile carrier,

$$T_i = \frac{n-1}{n(1-s_j)} (a - c_O^F - c_1 - s_j \mathbf{t} + \frac{1-s_j}{n-1} c_T^M).$$

Solving for the fixed-to-mobile price:

$$P = \frac{1}{2n} \left( (2n-1)a + c_O^F + c_1 - s_j \mathbf{t} + (1-s_j) c_T^M \right)$$

Note that  $P > P^m$  even if  $\mathbf{t} = c_T^M$  so long as  $n \geq 2$ . In other words, even if the regulator requires the dominant carrier to set its termination price at marginal cost, the resultant fixed-to-mobile price will always exceed the integrated monopoly price whenever there is at least one other mobile carrier.

We can show that regulation of one mobile carrier leads to lower fixed-to-mobile prices than no regulation so long as the regulated price does not exceed the marginal termination cost by too much. To see this, let  $\Delta P$  denote the difference between the fixed-to-mobile price with one mobile carrier regulated and the price with no regulation but the same total number of mobile carriers. Then  $\Delta P = \frac{1}{2n(n+1)} \left( -a + c_O^F + c_1 + c_T^M + (n+1)s_j(\mathbf{t} - c_T^M) \right)$ . This will be negative so long as  $\mathbf{t} - c_T^M$  is not too positive.

This said, the effect of regulation in reducing the equilibrium fixed to mobile price is small compared to the effect of additional mobile carriers in raising this price. To see this, suppose that one carrier is regulated but at the same time there is one more mobile carrier. In other words, while the dominant carrier is regulated, another unregulated mobile carrier enters the

industry. In this case, let the change in price under regulation with an extra mobile firm compared to the case of no regulation with one less mobile firm be denoted by  $\Delta\bar{P}$ . Then  $\Delta\bar{P} = \frac{1}{2(n+1)}(s_j(\mathbf{t} - c_T^M))$ . This is positive if  $\mathbf{t} - c_T^M$  is positive.

It is worth considering the case of two firms in more detail. In this situation, the dominant firm  $j$  is regulated but the other mobile carrier remains unregulated. Solving for the termination charge of the unregulated firm we find that  $T_i = \frac{1}{2s_j}(a - c_O^F - c_1 - s_j\mathbf{t} + s_i c_T^M)$ . The fixed carrier will then set the price of fixed to mobile calls so that  $P = \frac{1}{4}(3a + c_O^F + c_1 + s_j\mathbf{t} + s_i c_T^M)$ . Note that this is not only greater than the integrated monopoly price but is also above the double-marginalisation price whenever  $\mathbf{t} - c_T^M$  is positive. This reflects  $\Delta\bar{P}$  as calculated above. The quantity of fixed to mobile calls in this situation will be  $Q = \frac{1}{8b}(a - c_O^F - c_1 - s_j\mathbf{t} - s_i c_T^M)$ . The profits of the unregulated carrier are given by  $\frac{1}{16b}(a - c_O^F - c_1 - s_j\mathbf{t} - s_i c_T^M)^2$ . Note that these profits are decreasing in  $\mathbf{t}$ . The unregulated mobile carrier prefers to have a more tightly regulated competitor. This follows because lowering the regulated carriers' allowed termination charge tends to lower the average price of fixed-to-mobile calls. This provides the unregulated carrier more freedom to raise its termination charges and increase its profits. The profits of the fixed carrier in this situation are given by  $\frac{1}{32b}(a - c_O^F - c_1 - s_j\mathbf{t} - s_i c_T^M)^2$ . Note that when  $\mathbf{t} = c_T^M$  then these profits are equal to the fixed carrier's profits under standard double marginalisation.

While we have referred to the regulation in this section as applying to the dominant carrier, nothing in the above discussion depends on this. For example, if regulation involved setting the termination charge for one carrier equal to cost, the basic results for the two-carrier case would be unchanged regardless of whether the regulated carrier had more or less than 50% of the market share.

### 4.3.7 Regulation by setting the fixed-to-mobile price

One final alternative should be noted before we move to the case with vertical integration. While the above analysis has considered the regulation of the termination charges set by the mobile carriers, a more direct solution to the problem of fixed-to-mobile charges might be the direct regulatory setting of the fixed-to-mobile call price. Setting the end price for fixed-to-mobile calls avoids some of the problems with regulating mobile termination charges directly. In particular, it avoids issues of regulating firms that only have a relatively small market share. Once the final price was established, termination charges would then simply be a device used by the carriers to divide any profit that exists under the regulation. While the setting of these charges could lead to considerable dispute, such a dispute is more about sharing profits than about raising prices to the detriment of final customers.

## 4.4 Unregulated Outcomes Under Integration

We now consider the case where the fixed carrier also owns one of the mobile carriers. For simplicity, we refer to this as the case of *integration*. In this situation, the mobile carrier that is owned by the fixed carrier cannot effectively raise its marginal termination charge above marginal cost. Any such increase would merely transfer funds from the fixed carrier to the mobile carrier. But as the same company owns these carriers, these transfers would simply be internal to the company. A manager or owner who sought to maximise the total profits of the company would disregard such internal transfers as they have no effect on the profit of the company as a whole.

With integration, the fixed carrier will take the price of terminating calls to mobile phone networks other than its own as given, and will set the price of fixed-to-mobile calls to maximise company profits. Let  $s_F$  refer to the fraction of mobile phone customers who are subscribers to the mobile carrier that is owned by the fixed carrier. From section 2.1, the integrated carrier will maximise:

$$\max_P (P - c_O^F - c_1 - s_F c_T^M - \sum_{i \neq F} s_i T_i) Q(P)$$

The solution to this problem is given by  $P = \frac{1}{2}(a + s_F c_T^M + \sum_{i \neq F} s_i T_i + c_O^F + c_1)$  with associated quantity  $Q = \frac{1}{4b}(a - s_F c_T^M - \sum_{i \neq F} s_i T_i - c_O^F - c_1)$ . Given the behaviour of the fixed carrier, the non-integrated mobile networks will simultaneously set their termination charges to solve:

$$\max_{T_i} \frac{s_i}{4b} (T_i - c_T)(a - s_F c_T^M - \sum_{j \neq F} s_j T_j - c_O^F - c_1).$$

The first order condition for the mobile carriers optimisation is given by

$$a - s_F c_T^M - \sum_{j \neq F} s_j T_j - 2s_i T_i - c_O^F - c_1 + s_i c_T^M = 0.$$

Solving these first order conditions simultaneously for all mobile carriers gives the Nash equilibrium termination charges.

The first order conditions for the fixed and non-integrated mobile carriers are mathematically identical to the case of no integration but direct regulation of a dominant mobile carrier with  $t = c_T^M$ . Consequently, the results with integration will be directly analogous to this situation. For example, if there are  $n$  mobile carriers in total and each non-integrated carrier has an equal market share, then the termination price for the  $(n-1)$  non-integrated carriers will be given by

$$T_i = \frac{n-1}{n(1-s_F)} (a - c_O^F - c_1 - s_F c_T^M + \frac{1-s_F}{n-1} c_T^M)$$

Given these termination charges the fixed-to-mobile price is given by:

$$P = \frac{1}{2n} ((2n-1)a + c_O^F + c_1 - (2s_F - 1)c_T^M)$$

Similarly, if there are only two mobile carriers, one integrated and one not integrated, then  $T_i = \frac{1}{2}(a - c_O^F - c_1 + c_T^M)$ ,  $P = \frac{1}{4}(3a + c_{FM}) > P^m$  and  $Q = \frac{1}{8b}(a - c_{FM})$ .

From  $\Delta \bar{P}$  above with  $t = c_T^M$ , integration together with entry by one extra non-integrated mobile carrier leads to no change in the price of fixed-to-

mobile calls. Or, in other words, integration of one mobile carrier with the fixed carrier is equivalent to ‘losing’ one mobile carrier in terms of the effect on price. For example, if there are only two carriers, one of which is integrated with the fixed carrier, then the price of fixed-to-mobile calls in equilibrium is the same as the ‘double marginalisation’ price with only one non-integrated carrier. In this case the non-integrated mobile carrier’s profits are equal to  $\frac{1}{16b}(a - c_{FM})^2$  – the same as if it were the only mobile carrier. The integrated carrier makes profits  $\frac{1}{32b}(a - c_{FM})^2$ . These are the same as if it did not own a mobile carrier and there was only one non-integrated mobile carrier.

The fact that integration with a mobile carrier generates no additional profits for the fixed carrier, but raises the price of fixed-to-mobile calls and increases the profits of the non-integrated mobile carriers, suggests that the fixed carrier might have no incentive to integrate. Or, if it is initially integrated, then the fixed carrier might have incentives to separate from its mobile carrier, particularly in the longer term when market shares of mobile carriers have ‘settled down.’ To confirm this, note that if there are  $n$  symmetric non-integrated mobile carriers, then the fixed carrier makes profit of  $\Pi_F = \frac{1}{8b(n+1)^2}(a - c_{FM})^2$  while each mobile carrier makes profit of  $\Pi_M = \frac{1}{4b(n+1)^2}(a - c_{FM})^2$ . In contrast, if the fixed carrier is integrated with one of the  $n$  mobile carriers, then the integrated carrier makes total profits  $\Pi_I = \frac{1}{8bn^2}(a - c_{FM})^2$ . If the fixed carrier begins with vertical integration into the mobile market, then the fixed carrier will prefer to retain that structure only if they make more total profits through integration than through divesting their mobile carrier. Note that if they divest their mobile carrier, then in a competitive market for corporate control, the price that they receive for the mobile carrier (above the cost of the carrier’s assets) will equal the profits of the separate mobile carrier. So the integrated firm will prefer to remain integrated only if  $\Pi_I \geq \Pi_F + \Pi_M$ . Similarly, if the fixed carrier currently does not own a mobile carrier, then it will only want to buy such a carrier if this

raises its profits. In a competitive market for corporate control, the price of a non-integrated mobile carrier (above the cost of the carrier's assets) will be equal to the profit of a non-integrated carrier. So the fixed carrier will only seek to buy a mobile carrier if the profits of the integrated carrier, less the cost of the mobile carrier, is greater than the profit of a stand-alone fixed carrier,  $\Pi_I - \Pi_M \geq \Pi_F$ . These two inequalities are clearly identical. Simplifying, it is only profitable to be an integrated carrier if  $\frac{1}{8bn^2}(a - c_{FM})^2 \geq \frac{3}{8b(n+1)^2}(a - c_{FM})^2$  or  $2n^2 - 2n - 1 \leq 0$ . Solving this quadratic equation means that there is only an incentive to integrate if  $n \leq 1.37$ .

To interpret this result, if all mobile carriers are symmetric, then integration will only be a stable long-run outcome if there is only one mobile carrier. The logic behind this is clear. Integration with one mobile carrier avoids double marginalisation and raises total profits. But for two or more mobile carriers, it is better not to integrate. In this case, the non-integrated mobile carrier seizes all the benefits of integration, and integration actually makes the fixed carrier worse off.

There are two clear caveats to this result. First, if owning the fixed carrier makes it easier to gain mobile customers and increase market share then integration is more likely to be desirable. This could occur through reputation or marketing. Secondly, if market shares are not symmetric then integration with the largest of the mobile carriers may be desirable even though there are two or more mobile carriers. This effect will tend to decrease as the number of mobile carriers rises and market shares become more equal over time.

## 4.5 Regulation Under Integration

We now revisit our regulatory options for the case where one mobile network is integrated with the fixed network. As will be demonstrated, the conclusions reached are essentially the same as the non-integrated case.

### 4.5.1 Bargaining between the integrated and the mobile carriers

As in the case without integration, if bargaining is efficient then all external spillover effects between the integrated and the separate mobile carriers will be internalised. The efficient bargaining outcome will lead to monopoly pricing with marginal termination charges for all mobile carriers set at marginal cost. Profits will be divided between carriers using non-linear pricing.

### 4.5.2 Direct mobile charging

With integration and direct mobile charging, the integrated carrier sets both the originating charge for fixed to mobile calls  $O$  and the terminating charge for its own mobile carrier  $T_F$ . The other separated mobile carriers just set their termination fees,  $T_i$ . The fixed carrier will solve:

$$\max_{O, T_F} \frac{1}{2b} (a - O - s_F T_F - \sum_{i \neq F} s_i T_i) (O + s_F T_F - c_O^F - c_1 - s_i c_T^M)$$

The first order conditions for profit maximisation are given by

$$(O) : a - 2O - 2s_F T_F - \sum_{i \neq F} s_i T_i + c_O^F + c_1 + s_F c_T^M = 0$$

$$(T_F) : s_F (a - 2O - 2s_F T_F - \sum_{i \neq F} s_i T_i + c_O^F + c_1 + s_F c_T^M) = 0$$

Notice that these two first order conditions are identical. Given its share of the mobile market, the integrated carrier simply sets  $O + s_F T_F$  to maximise profits.

The separated mobile carriers will set their termination charges to maximise

$$\max_{T_i} \frac{1}{2b} (a - O - \sum_j s_j T_j) (s_i T_i - s_i c_T^M)$$

The first order condition for profit maximisation is  $a - O - 2s_i T_i - \sum_{j \neq i} s_j T_j + s_i c_T^M = 0$ .

We can use these first order conditions to calculate the equilibrium under direct mobile charging. For example, if there are only two mobile carriers, one of which is integrated with the fixed carrier then the expected total price is  $P = \frac{1}{3}(2a + c_{FM})$ . Note that this is the same expected total price as

with direct mobile charging with one non-integrated mobile carrier. Similarly, suppose that the  $n$  mobile carriers, including the integrated mobile carrier, have equal market shares. Then from the first order conditions, we can solve for the expected total price of fixed-to-mobile calls as  $P = \frac{1}{n+1}(na + c_{FM})$ . Again note that this is identical to the expected total price under direct mobile charging with  $n-1$  mobile carriers and no integration. In other words, the only effect of integration on mobile direct charging is to effectively ‘remove’ one mobile carrier from the market.

### 4.5.3 Carrier identification

If the carrier was identified, then the situation is identical to the case without integration, except that the integrated firm will always set the integrated monopoly price for its fixed-to-mobile calls regardless of the degree of substitution between mobile carriers. Again, as substitution increases, the price of all fixed to mobile calls will decline until it reaches the integrated monopoly price under perfect substitution.

### 4.5.4 Direct setting of termination charges

If all carriers except the integrated carrier have their termination charges set equal to  $t$ , then the price of fixed-to-mobile calls will equal  $P = \frac{1}{2}(a + c_O^F + c_1 + s_F c_T^M + (1 - s_F)t)$ . There is clearly no point in setting the integrated carriers termination charge as this is merely an internal transfer for the firm.

This situation is again identical to the case without integration except that the regulated termination price  $t$  now has less effect on the price of fixed-to-mobile calls.

## 5 Mobile Network Competition

The previous analysis has made a critical assumption: that the market shares of the mobile networks were fixed and did not change as termination charges, fixed to mobile and mobile to mobile prices changed. This assumption would be reasonable in environments where mobile networks were not in strong competition with one another. For example, the networks may cover different geographic areas or may operate with distinct technologies that appealed to different customer groups. In reality, however, mobile networks – as do many telecommunication networks – compete with one another for market share. This competition is critically influenced by the costs and quality of their service and to the extent that these are influenced by termination charges they are of relevance to the present study.

Given this, it is appropriate to develop a model of mobile network competition in order to understand the determinants of the market shares of competing networks. We envisage negotiations or regulation of termination charges as occurring prior to the competition between mobile networks for customers. Consequently, we will take those charges as given as the model is developed. We will then be in a position to consider the impact of negotiated outcomes and alternative regulatory rules.

### 5.1 The Players

Our starting point is as in the previous sections. We suppose that there are two mobile networks,  $A$  and  $B$ , and a single fixed line network,  $F$ . The fixed network has a set of customers of measure  $n$  while the mobile networks compete for a customer set of measure 1. One can, therefore, interpret  $n$  as the measure of relative size of the fixed customer base to the mobile base. We assume that these overall shares are fixed: in effect, fixed and mobile customers are distinct and the two forms of telecommunication are not

competitors. We will consider the implications of relaxing this assumption towards the end of this section.

## 5.2 Technological Assumptions

We maintain our notation from the previous section but add some new definitions. In particular,

- $c_T^F$  is the marginal cost of termination on the fixed network
- $c_O^M$  is the marginal cost of origination on either mobile network
- $c_1$  is the marginal trunk cost incurred by fixed and mobile networks either to each other
- $f$  is the cost of connecting a consumer to a mobile network

Thus, mobile and fixed networks can potentially have different cost structures.

## 5.3 Customer Preferences

We suppose that the two mobile networks –  $A$  and  $B$  – sell a differentiated but substitutable product. We model this by assuming that each network is located at either end of a line of length 1 with  $A$  located at 0 and  $B$  located at 1. Consumers are located uniformly over the line. Given income  $y$ , outgoing calls  $q$  and incoming calls  $z$ , a consumer located at  $x$  and joining network  $i$  has utility:

$$y + v_0 - t|x - x_i| + u(q, z)$$

where  $v_0$  represents a consumer's intrinsic value of having a mobile phone and  $t|x - x_i|$  denotes the cost of being to a network with 'address'  $x_i$  ( $i = A, B$ ).<sup>14</sup>

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<sup>14</sup> This is essentially the model structure of Laffont, Rey and Tirole (1998a, 1998b).

It is interesting to consider in more detail the potential interaction between incoming and outgoing calls in a consumer's utility function. It is possible that a consumer may realise no utility from incoming calls,  $z$ . This could be because they do not like incoming calls and switch their phones off or they do not place value on being contactable by that method. Nonetheless, other consumers may place value on calling a particular consumer. The point, however, is that when a consumer is indifferent as to the value of  $z$ , the price of this will not be a factor in determining their network choice.

An alternative situation is where the consumer cares about how many calls they may receive but not specifically about the price of these calls. Finally, some consumers may realise that if there is a price differential between incoming and outgoing calls, then it pays to make the caller the person with facing the lowest price. In this case, if such a consumer is called by someone on a fixed line and the price of fixed to mobile is greater than the reverse, then that consumer will call them back to minimise their joint calling cost.

Initially we begin with the case of caller indifference and leave it to later in this section to explore the implications of consumer preferences for incoming calls.

## 5.4 Pricing and the Determination of Market Shares

We are now in a position to consider the determinants of consumer choice between mobile carriers. Let  $v(p)$  be the indirect utility function of a consumer who faces an outgoing call price of  $p$  (per call or call-minute) (i.e.,  $v(p) \equiv \max_q u(q) - pq$ ). We interpret this, as do Laffont, Rey and Tirole (1998b), as the utility generated from calling a particular person. Implicitly, this means that consumers do not refrain from calling people when the price of doing so rises but merely that they call them for less often or for smaller periods of time. Basically, ours is a per period expected utility calculation.

We will assume that mobile consumers can be offered non-linear prices, i.e., a two-part tariff. That is,

$$W_i(q_i, q_{ij}, q_{iF}) = F_i + p_i q_i + p_{ij} q_{ij} + p_{iF} q_{iF}$$

where:

- $F_i$  is the fixed fee or subscriber charge;
- $p_i$  is the per call charge from network  $i$ ;
- $q_i$  is the quantity of calls to network  $i$ ;
- $p_{ij}$  is the per call charge from network  $i$  to network  $j$
- $T_{ij}$  is the termination charge from network  $i$  to network  $j$
- $q_{ij}$  is the quantity of calls from network  $i$  to network  $j$  divided by  $i$ 's market share
- $p_{iF}$  is the per call charge from network  $i$  to network  $F$
- $T_{iF}$  is the termination charge from network  $i$  to network  $F$
- $q_{iF}$  is the quantity of calls from network  $i$  to network  $F$  divided by  $i$ 's market share.

$p_{Fi}$ ,  $T_{Fi}$  and  $q_{Fi}$  are the reverse charges and flows for the last three variables, respectively. Value for a consumer subscribing to networks  $A$  and  $B$  are therefore:

$$V_A = \frac{1}{n+1}(\mathbf{a}v(p_A) + (1-\mathbf{a})v(p_{AB})) + \frac{n}{n+1}v(p_{AF}) - F_A$$

$$V_B = \frac{1}{n+1}(\mathbf{a}v(p_{BA}) + (1-\mathbf{a})v(p_B)) + \frac{n}{n+1}v(p_{BF}) - F_B$$

where  $\mathbf{a}$  is the market share (among mobile consumers) of network  $A$ . Notice that this specification implicitly includes our assumption that consumers choose their calling patterns among networks randomly; save for differing call prices.

The market share of network  $A$ ,  $\mathbf{a}$ , is determined by the point of indifference between  $A$  and  $B$ . That is,

$$V_A - \mathbf{a} = V_B - t(1 - \mathbf{a})$$

$$\Rightarrow \mathbf{a} = \frac{1}{2} + \mathbf{s}(V_A - V_B)$$

where  $\mathbf{s} = 1/(2t)$  is the degree of substitutability between the two mobile networks.

Note that in bidding for customers, each network will find it optimal to set each call charge equal to its marginal cost. Focusing on network  $A$ , these usage prices are:  $p_A = c_1 + c_O^M + c_T^M$ ,  $p_{AB} = c_1 + c_O^M + T_{BA}$ , and  $p_{AF} = c_1 + c_O^M + T_{FA}$ . This is a common outcome when firms can set multi-part tariffs. Basically, it is in a network's interest to set non-distortionary tariffs. When price is set equal to marginal cost, the sum of consumer surplus and that network's per customer profits is maximised. If this were the only component of pricing, the network may not recover any fixed costs, e.g., customer connection costs. However, the fixed charge,  $F_A$ , can be utilised to divide total value created (that is, utility less costs).<sup>15</sup>

Given that usage charges are set equal to a network's marginal cost for various services, the market share of network  $A$  becomes:

$$\mathbf{a} = \frac{\frac{1}{2} + \mathbf{s} \left( \frac{1}{n+1} \Omega + F_B - F_A \right)}{\left( 1 - \frac{1}{n+1} \mathbf{s} \Lambda \right)} \quad (5.1)$$

where

$$\Lambda = (2v(c_O^M + c_1 + c_T) - v(c_1 + c_O^M + T_{BA}) - v(c_1 + c_O^M + T_{AB})) \text{ and}$$

$$\Omega = v(c_1 + c_O^M + T_{BA}) - v(c_O^M + c_1 + c_T^M) + nv(c_1 + c_O^M + T_{FA}) - nv(c_1 + c_O + T_{FB}).$$

Note that an interior equilibrium exists if  $1 > \frac{1}{n+1} \mathbf{s} \Lambda$ ; that is, so long as termination charges and the degree of substitution are not too high.

Looking at equation (5.1), we can see how the various termination charges impact upon the market shares of the mobile networks – taking their own charges as given. These comparative statics are summarised in the following proposition.

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<sup>15</sup> For a discussion of this see King and Maddock (1996).

**Proposition 5.1.** Assume that  $1 > \frac{1}{n+1} \mathbf{s}\Lambda$  and  $\mathbf{a} \in (0,1)$ . Taking  $F_A$  and  $F_B$  as given,  $\mathbf{a}$  is increasing in  $T_{AB}$ , and  $T_{FB}$  and decreasing in  $T_{BA}$  and  $T_{FA}$ .

Intuitively, when the termination charges that  $A$  pays to other carriers falls and those that  $B$  pays to other carriers rises, the relative value that  $A$  provides to its customers rises, as does its market share. With two-part tariffs, higher per unit termination charges are passed through to customers, lowering their utility. If one network faces lower terminating costs on other networks this will enhance their ability to attract customers to their network.

## 5.5 Equilibrium Mobile Charges

We now turn to consider each network's choice of subscription charges –  $F_A$  and  $F_B$  and  $A$  and  $B$ , respectively. Each network will choose their charge to maximise its profits taking the other network's prices as given. In a Nash equilibrium (if it exists), each network will be satisfied with their choices and find unilateral deviations unprofitable.

Given that usage charges are set equal to a network's marginal cost for various services, network  $A$ 's profit is, therefore,

$$\mathbf{p}_A = \mathbf{a}(F_A - f) + \frac{n}{n+1} \mathbf{a}(T_{AF} - c_T^M) q_{FA} + \frac{1}{n+1} \mathbf{a}(1 - \mathbf{a})(T_{AB} - c_T^M) q_{BA}.$$

This profit is the sum of the network's profits from its own customers, and also the revenue realised from its termination calls from the fixed and other mobile networks respectively, as their customers call its customers.  $A$  will choose  $F_A$  to maximise these profits, yielding the first order condition:

$$\frac{\partial \mathbf{p}_A}{\partial F_A} = \mathbf{a} + \frac{\partial \mathbf{a}}{\partial F_A} \left( F_A - f + \frac{n}{n+1} (T_{AF} - c_T^M) q_{FA} + (1 - 2\mathbf{a}) \frac{1}{n+1} (T_{AB} - c_T^M) q_{BA} \right) = 0 \quad (5.2)$$

where

$$\frac{\partial \mathbf{a}}{\partial F_A} = - \frac{\mathbf{s}}{(1 - \frac{1}{n+1} \mathbf{s}\Lambda)}$$

Raising its charge increases the direct revenues  $A$  earns from its inframarginal customers. However, it also drives away marginal customers. This is costly

because not only does  $A$  lose its direct revenues but also the termination revenues it would otherwise receive from customers on other networks calling that customer.  $B$  faces the same trade-off in determining its pricing.

The important thing to note here is that the existence of termination revenues makes networks tougher price competitors (especially when they have less than half of the customers). This is because, when networks discount to gain a customer, they also attract the calls from other networks to that customer. However, they internalise within their own network calls made by that customer to their own customers and this causes a reduction in termination revenues. Nonetheless, so long as their market share is not too high, this makes the marginal customer more valuable and hence, bidding for that customer more intense.

Secondly, note that

$$\begin{aligned}\frac{\partial^2 p_A}{\partial F_A \partial T_{FA}} &= \frac{\partial a}{\partial T_{FA}} \left( 1 - 2 \frac{\partial a}{\partial F_A} \frac{1}{n+1} (T_{AB} - c_T^M) q_{BA} \right) \leq 0 \\ \frac{\partial^2 p_A}{\partial F_A \partial T_{FB}} &= \frac{\partial a}{\partial T_{FB}} \left( 1 - 2 \frac{\partial a}{\partial F_A} \frac{1}{n+1} (T_{AB} - c_T^M) q_{BA} \right) \geq 0 \\ \frac{\partial^2 p_A}{\partial F_A \partial T_{BA}} &= \frac{\partial a}{\partial T_{BA}} \left( 1 - 2 \frac{\partial a}{\partial F_A} \frac{1}{n+1} (T_{AB} - c_T^M) q_{BA} \right) \\ &\quad + \frac{\partial^2 a}{\partial F_A \partial T_{BA}} \left( F_A - f + \frac{n}{n+1} (T_{AF} - c_T^M) q_{FA} + (1 - 2a) \frac{1}{n+1} (T_{AB} - c_T^M) q_{BA} \right) \leq 0\end{aligned}$$

This means that an increase in  $T_{FA}$  or  $T_{BA}$  or a decrease in  $T_{FB}$  will make  $A$  a tougher price competitor. As we will demonstrate below, these forces mean that mobile networks will be reluctant to raise termination charges and the fixed network may be able to use discriminatory termination charges to allow one mobile network to achieve a dominant position.

Finally, observe that:

$$\frac{\partial^2 p_A}{\partial F_A \partial T_{AF}} = \frac{\partial a}{\partial F_A} \frac{n}{n+1} \left( q_{FA} + (T_{AF} - c_T^M) \frac{\partial q_{FA}}{\partial T_{AF}} \right) \leq 0$$

This means that an increase in  $T_{AF}$  will result in a decrease in mobile charges whenever  $T_{AF}$  is below the level that maximises termination profits and will increase those charges otherwise.

So long as  $\mathbf{s}$  is low enough (i.e., networks are poor substitutes) and  $T_{AB}$  and  $T_{BA}$  are close to  $c_T^M$  (i.e., mobile interconnection profits are not too large), then there exists a unique (Nash) equilibrium. For this general case, the equilibrium values of  $F_A$  and  $F_B$  are complex and we list them in Appendix A. Here we take a closer look at the equilibrium market share of network  $A$ :

$$\mathbf{a} = \frac{1}{2} + \mathbf{s} \frac{\Omega + \frac{1}{2}\Lambda + n((T_{AF} - c_T^M)q_{FA} - (T_{BF} - c_T^M)q_{FB})}{3(1 + n - \mathbf{s}\Lambda) + 2\mathbf{s}(T_{AB} + T_{BA} - 2c_T^M)q_{BA}} \quad (5.3)$$

Notice that when  $T_{AF} = T_{BF}$  and  $T_{FA} = T_{FB}$  and  $T_{AB} = T_{BA}$ ,  $\mathbf{a}$  is equal to  $\frac{1}{2}$ . When  $T_{AB} > T_{BA}$ ,  $\mathbf{a} \geq \frac{1}{2}$  as the greater interconnect revenues  $A$  receives improves its position to compete on price. On the other hand,  $T_{FA} > T_{FB}$  results in  $\mathbf{a} < \frac{1}{2}$  as this raises the costs of mobile to fixed calls from  $A$ 's network and hence, value afforded to its customers. As such, it is possible for the fixed network to use discriminatory pricing of its termination charges to favour one network.

## 5.6 Mobile-To-Mobile Termination Charges

We view termination charges as being set prior to competition for mobile customers. This need not be taken literally. It is a modelling technique that captures an assumption that charges to mobile consumers can be more easily changed than termination charges negotiated between networks. Here we look at the termination charges that would be set between  $A$  and  $B$ .

We begin by considering what happens when  $A$  and  $B$  set their termination charges independently. While a precise solution is not possible we can demonstrate the following:

**Proposition 5.2.** *Assume that fixed to mobile and mobile to fixed termination charges and prices are the same for A and B. Then, in any symmetric Nash equilibrium,  $T_{AB} = T_{BA} > c_T^M$ .*

PROOF: Without loss in generality, suppose that  $n = 0$ . Then A's profits (taking into account the interior equilibrium values of  $F_A$  and  $F_B$ ) are:

$$p_A = \frac{1+s(T_{AB}-c_T^M)q_{BA}-s\Lambda}{4s} \left( 1+2s \frac{\Omega+\frac{1}{2}\Lambda}{2s(T_{AB}+T_{BA}-2c_T^M)q_{BA}+3(1-s\Lambda)} \right)^2 \quad (5.4)$$

where now  $\Omega = v(c_1+c_O^M+T_{BA})-v(c_1+c_T^M+c_O^M)$ . Taking the derivative of this with respect to  $T_{AB}$  and setting  $T_{AB} = T_{BA} = c_T^M$ , we have:  $-\frac{1}{6}v'(c_1+c_O^M+c_T^M) > 0$  implying that at this point A (and symmetrically B) would increase its profits by raising  $T_{AB}$  ( $T_{BA}$ ).

This outcome is akin to the standard double marginalisation result that arises when firms set prices for complementary services independently. What this means is that prices are higher than they otherwise would be and profits and consumer surplus are lower.

Consumer surplus is reduced because the price for mobile-to-mobile calls between networks is too high and hence, fewer calls are made. This also raises the possibility that a symmetric equilibrium may not exist. The termination charges mean that the mobile network with a greater number of subscribers will face lower average call costs. If networks were close substitutes this may lead to a cornered solution with all subscribers on a single network. Here we have ruled out this possibility by our assumption that networks are not close substitutes so that the equilibrium remains interior.

On the profit side, in a symmetric equilibrium, under the assumptions regarding fixed to mobile and mobile to fixed charges, A's profits are:

$$p_A = \frac{1}{4s} - \frac{m(c_1+c_O^M+c_T^M)v'((1+m)(c_1+c_O^M+c_T^M))+2(v(c_1+c_O^M+c_T^M)-v((1+m)(c_1+c_O^M+c_T^M)))}{4(1+n)} \quad (5.5)$$

where, following Laffont, Rey and Tirole (1998b),  $T_{AB} = T_{BA} = m(c_1+c_O^M+c_T^M)+c_T^M$  and, by Shepherd's Lemma,  $q_{AB} = q_{BA} = -v'((1+m)(c_1+c_O^M+c_T^M))$ . Notice that these profits are maximised

when  $m$  is low.<sup>16</sup> For example, if termination charges equal the marginal cost of termination, i.e.,  $m = 0$ , profits equal  $1/(4s)$  that is the same level of profits that would arise in Hotelling competition with unit demands (see Tirole, 1988).

However, it is possible that  $m < 0$  could increase profits further. The rationale is as follows: when a mobile network is considering lowering its subscription charge to attract a customer, not only does it attract a customer's call revenue but also the termination revenue from others calling that customer from the rival network. When  $m > 0$ , such termination revenue exceeds termination costs and so induces a network to be more aggressive in pricing. However, when  $m < 0$ , call termination becomes a liability rather than a benefit. Hence, an agreement on this softens price competition and raises equilibrium firm profits above  $1/(4s)$ . For instance, a commonly used rule – bill and keep – effectively sets  $m = -c_T^M / (c_1 + c_O^M + c_T^M)$ ; making termination a cost rather than a benefit.

What this implies is that if  $A$  and  $B$  were to negotiate a reciprocal interconnect charge, they would choose  $m < 0$  as this maximised their joint profit. This type of negotiated outcome, by eliminating the double marginalisation problem, would raise consumer surplus on mobile to mobile calls by lowering inter-network mobile prices. However, the negotiated outcome is not a (constrained) social optimum because consumers are bearing the deadweight losses associated with low mobile to mobile rates in higher subscription charges.

This result stands in contrast to other conclusions regarding the potential anti-competitive effect of negotiated interconnect fees. Armstrong

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<sup>16</sup> As demonstrated by Laffont, Rey and Tirole (1998b, Proposition 5). Note that:

$$\frac{\partial p_A}{\partial m} = -\frac{c_1 + c_O^M + c_T^M}{4(1+n)} \left( m(c_1 + c_O^M + c_T^M) v''((1+m)(c_1 + c_O^M + c_T^M)) - v'((1+m)(c_1 + c_O^M + c_T^M)) \right) < 0.$$

Hence, increasing  $m$  reduces profits.

(1998), Carter and Wright (1998) and Laffont, Rey and Tirole (1998a) all find that interconnect charges will be negotiated to be above  $c_T^M$  in order to soften price competition among networks. Indeed, it is possible to utilise the interconnect fee to induce monopoly pricing and profit outcomes without explicit (or tacit) collusion on prices to final consumers. Such anti-competitive outcomes arise for two reasons. First, network competition does not take place with two-part tariffs. Instead, in each of those papers, networks offer simple usage charges to consumers. This means that a higher interconnect fee, by raising a rival's marginal cost, softens their ability to compete on price. If such fees are negotiated, a monopoly-pricing outcome can be effectively negotiated. Second, networks do not price discriminate between on and off-network calls. In our model here price discrimination is possible and consumers can respond to any price differences. This makes it more difficult to use the interconnect fee as a collusive device to raise intra-network call prices, but it does make it possible to use it to lower inter-network prices. Combined with two-part tariff competition, a high interconnect fee becomes a drain on profits as it merely serves to intensify price competition. In contrast, if customers were ignorant regarding which mobile network they were calling our price discrimination assumption could not be justified. With two-part tariffs, equilibrium profits would be independent of the interconnect fee. In this respect, although when they set interconnect fees non-cooperatively, each would still set termination charges above marginal cost, if the two networks were to negotiate they would be indifferent between all symmetric termination charges.<sup>17</sup>

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<sup>17</sup> See Laffont, Rey and Tirole (1998a).

## 5.7 Mobile-to-Fixed Prices

We can now turn to consider the termination charges that the fixed network will set for calls from mobiles to its network. Given our assumptions regarding mobile customer preferences, the fixed network's profit with respect to its termination service is:

$$\mathbf{p}_F = \mathbf{a}(T_{FA} - c_T^F)(-v'(c_1 + c_T^M + T_{FA})) + (1 - \mathbf{a})(T_{FB} - c_T^F)(-v'(c_1 + c_T^M + T_{FB})) \quad (5.6)$$

with  $\mathbf{a}$  as in (5.3). The first derivatives of this with respect to  $T_{FA}$  and  $T_{FB}$  are:

$$\begin{aligned} \frac{\partial \mathbf{p}_F}{\partial T_{FA}} &= \frac{\partial \mathbf{a}}{\partial T_{FA}} \left( (T_{FA} - c_T^F)(-v'(c_1 + c_T^M + T_{FA})) - (T_{FB} - c_T^F)(-v'(c_1 + c_T^M + T_{FB})) \right) \\ &\quad - \mathbf{a} \left( v'(c_1 + c_T^M + T_{FA}) + (T_{FA} - c_T^F) v''(c_1 + c_T^M + T_{FA}) \right) = 0 \end{aligned}$$

$$\begin{aligned} \frac{\partial \mathbf{p}_F}{\partial T_{FB}} &= \frac{\partial \mathbf{a}}{\partial T_{FB}} \left( (T_{FA} - c_T^F)(-v'(c_1 + c_T^M + T_{FA})) - (T_{FB} - c_T^F)(-v'(c_1 + c_T^M + T_{FB})) \right) \\ &\quad - (1 - \mathbf{a}) \left( v'(c_1 + c_T^M + T_{FB}) + (T_{FB} - c_T^F) v''(c_1 + c_T^M + T_{FB}) \right) = 0 \end{aligned}$$

Note that  $\frac{\partial \mathbf{a}}{\partial T_{FA}} \leq 0$  and  $\frac{\partial \mathbf{a}}{\partial T_{FB}} \geq 0$ . Once again, so long as  $\mathbf{s}$  is not too high, and networks are otherwise symmetric,  $T_{FA} = T_{FB} = T_F$  where:

$$v'(c_1 + c_T^M + T_F) + (T_F - c_T^F) v''(c_1 + c_T^M + T_F) = 0$$

That is,  $T_F$  is the simple monopoly price and given the competition between mobile networks (based on two-part tariffs) results in a monopoly pricing outcome for mobile to fixed prices. Effectively, the fixed network is able to leverage its monopoly position completely.

This assumes posted price setting. However, when a mobile network and the fixed network negotiate over these charges the outcome will be the same. This is because  $T_F$  is the price that maximises the joint profits between the two networks; given that those negotiations cannot set the actual mobile to fixed call price.

It is possible, however, that competition between mobile networks is sufficiently intense that the fixed network prefers to favour a single network and charge a higher price to the other mobile carrier. This could drive that

market share of that carrier to zero and generate a mobile monopoly. The fixed and mobile networks would then share in the joint monopoly outcome. However, a complete analysis of this possibility is complex and beyond the scope of the present paper.

In this environment, regulation of the fixed network's termination charges could enhance social welfare. This would leave the conditions of mobile competition unchanged but would reduce dead-weight losses from monopoly pricing for mobile to fixed calls.

## 5.8 Fixed-to-Mobile Prices

As for the case of fixed market shares, the analysis of fixed-to-mobile prices and mobile network termination charges depends critically upon how informed consumers are regarding the network they are calling. If they cannot distinguish between alternative networks they will base their demand on a weighted price and the outcome will be as if the fixed network charged the same price for calls to each mobile network. On the other hand, if they can make such distinctions, price discrimination is possible.

We continue to assume consumer ignorance. This means that  $q_{FA} = q_{FB} = Q$ , where this is the linear demand case from the fixed market share model.<sup>18</sup> Recall that the price of fixed to mobile calls,  $P$ , is a monopoly price,  $P = \frac{1}{2}(a + \mathbf{a}T_{AF} + (1 - \mathbf{a})T_{BF} + c_O^F + c_1^F)$ . Given the equilibrium market shares, as defined by (5.3), the total quantity fixed to mobile calls is:

$$Q = \frac{3(1+n)(a - c_O^F - c_1^F - \frac{1}{2}(T_{AF} + T_{BF})) - n\mathbf{s}(v(c_1 + c_T^M + T_{FA}) - v(c_1 + c_T^M + T_{FB}))}{12b(1+n) + n\mathbf{s}(T_{AF} - T_{BF})^2}(T_{AF} - T_{BF})$$

Thus, as expected, an increase in the mobile termination charge results in an increase in  $P$  and a fall in  $Q$ . What this means is that if one network, say  $A$ ,

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<sup>18</sup> In the calculations that follow we have implicitly assumed that the networks do not consider their affect on  $Q$  when choosing subscription rates in stage 2. This makes the calculations simpler but we do not believe that relaxing this assumption would alter the substance of the results below.

increases its termination charge, this has a negative impact on the termination revenues of the other network, as it lowers the quantity of calls terminating on their network without any change in their termination charge.

This negative externality can be seen in the profit equation for network A (taking into account the interior equilibrium in competition for mobile customers):

$$p_A = \frac{1+n+s(T_{AB}-c_T)q_{BA}-s\Lambda}{4(1+n)s} \left( 1+2s \frac{nQ(T_{AF}-T_{BF})+\Omega+\frac{1}{2}\Lambda}{2s(T_{AB}+T_{BA}-2c_T)q_{BA}+3(1+n-s\Lambda)} \right)^2 \quad (5.7)$$

It is clear that as  $T_{BF}$  rises,  $p_A$  falls. A chooses  $T_{AF}$  to maximise these profits. The first order condition is:

$$Q + (T_{AF} - T_{BF}) \frac{\partial Q}{\partial T_{AF}} = 0$$

Essentially, the mobile networks act as relative revenue maximisers on their termination charges. The intuition here is that own revenue is passed on to final mobile customers through price competition unless termination revenue exceeds that of the other mobile network. If it does the difference can be appropriated. Consequently, mobile networks can maximise profits by ensuring that their termination revenues are high relative to the other network.

Consider a symmetric equilibrium where  $T_{AF} = T_{BF}$ . It is easy to see that in that equilibrium  $Q = 0$  or  $T_{AF} = T_{BF} = a - c_o^F - c_1^F$ . That is, mobile termination charges are set so high that demand for fixed to mobile calls reaches its ‘choke point’ as defined by  $P = a$ . The unique Nash equilibrium is this symmetric one if:

$$\begin{aligned} \left. \frac{dT_{AF}}{dT_{BF}} \right|_{T_{AF}=T_{BF}} &= - \frac{\partial Q / \partial T_{BF} - \partial Q / \partial T_{AF}}{2 \partial Q / \partial T_{AF}} < - \frac{\partial Q / \partial T_{AF} - \partial Q / \partial T_{BF}}{2 \partial Q / \partial T_{BF}} = \left. \frac{dT_{AF}}{dT_{BF}} \right|_{T_{AF}=T_{BF}} \\ &\Rightarrow \frac{\partial Q}{\partial T_{BF}} < - \frac{\partial Q}{\partial T_{AF}} \end{aligned}$$

which is true for  $T_{FA}$  close to  $T_{FB}$ .

The intuition here is simple. A network could improve its own termination revenues by setting its termination charge below  $a - c_o^F - c_1^F$ .

However, provided mobile networks are not close substitutes, this will confer a greater increment to termination revenue on the rival network. This is because that network enjoys the benefit of a positive number of fixed to mobile calls but a greater mark-up for those units. Consequently, while termination revenue may increase, relative revenue and hence, overall profits falls.

When the fixed network negotiates directly with the two mobile networks over their termination fees, assuming that they cannot feasibly use differential pricing to drive one mobile network's market share to zero, will choose termination charges  $T_{AF} = T_{BF} = c_T^M$ . From (5.7), observe that mobile network profits do not depend on the level of termination charges only their relative level. Hence, if these are identical, profits do not vary with termination charges. Consequently, the termination charges will be chosen to maximise the fixed network's profit only.

## 5.9 Preferences for Incoming Calls

In the above cases, when mobile termination charges are set independently, they tend to be above marginal cost, and in the case of termination charges for fixed calls, they may be set so high as to 'choke' off fixed to mobile demand. One possible reason for this may be our assumption that mobile consumers do not care about the quantity and hence, price of incoming calls from other networks. However, given our assumption of consumer ignorance, consumer preferences for incoming calls do not alter the above analysis.

To see this, suppose that mobile consumers cared about the quantity of calls they received from the fixed line network.<sup>19</sup> When evaluating which network to choose they will, therefore, look at more than simply the

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<sup>19</sup> Also, suppose the consumers were not 'large' in the sense that they commanded monopsony power.

subscription charge they face. They will also consider the fixed to mobile price charged to consumers and the quantity of calls received by the network. However, under consumer ignorance, fixed to mobile prices do not differ among networks. Therefore, regardless of which network they join, the quantity of incoming calls will be the same. It is only when consumers are aware of the network they are calling and the price of that network that consumer preferences for incoming calls will become salient and impact upon termination prices.

### 5.10 Vertical Integration

When a fixed and mobile network are vertically integrated all termination charges between them are effectively set at their respective marginal termination costs. Suppose  $A$  and  $F$  are integrated. Their joint profits become (assuming consumer ignorance regarding fixed to mobile calls):

$$p_A + p_F = a(F_A - f) + \frac{1}{1+n}a(1-a)(T_{AB} - c_T^M) + PQ + \frac{1}{1+n}(1-a)(T_{FB} - c_T^F)q_{BF} \quad (5.8)$$

while  $B$ 's profits remain as before. The key issue then becomes how the vertically integrated network will deal with the non-integrated mobile network. Vertical integration will enhance the incentives to foreclose on the non-integrated mobile network. However, we will continue to analyse an environment in which that network is able to maintain a positive market share.

Looking first at mobile-to-mobile termination charges, when those charges are reciprocal (i.e., so that  $T_{AB} = T_{BA}$ ) the same logic as the non-integrated case applies and the networks choose to set those charges at marginal termination cost. To see this, it is easy to calculate that, substituting in the equilibrium values of  $F_A$ ,  $F_B$  and  $P$ ,  $A$ - $F$ 's and  $B$ 's respective profits become:

$$p_A + p_F = \frac{1}{4s} + \frac{2s \left( v(c_1 + c_O^M + (1+m)c_T^M) - v(c_1 + c_O^M + c_T^M) \right) - mv'(c_1 + c_O^M + (1+m)c_T^M)}{4(1+n)} + \frac{(a - c_1 - c_O^F - c_T^M)(a + c_1 + c_O^F + c_T^M)}{8b}$$

$$p_B = \frac{1}{4s} + \frac{2s \left( v(c_1 + c_o^M + (1+m)c_T^M) - v(c_1 + c_o^M + c_T^M) \right) - mv'(c_1 + c_o^M + (1+m)c_T^M)}{4(1+n)}$$

where we have assumed that  $T_{BF} = c_T^M$  and  $T_{FB} = c_T^F$  and  $m$  is as before. Each of these increased by choosing a low  $m$ . So vertical integration does not appear to present further issues for the determination of mobile-to-mobile termination charges and prices.

The analysis of fixed to mobile and mobile to fixed prices is more complex. Basically, greater profits from the termination of fixed calls on  $B$ 's network make it a tougher price competitor. On the other hand, when  $A$ - $F$  loses a customer it suffers a reduction in profits as its must increase its fixed to mobile price. Thus, an increase in  $T_{BF} - c_T$  makes both networks tougher price competitors. On the other hand, when  $A$ - $F$  raises its termination charge for mobile calls on the fixed network, this makes  $B$  a weaker price competitor because it reduces customer value relative to  $A$  where the price of mobile to fixed calls is lower. While an exact calculation is not possible, we can prove the following.

**Proposition 5.3.** *Suppose that  $T_{AB} = T_{BA} = c_T^M$ . Then when  $A$ - $F$  post a price  $T_{FB}$  and  $B$  posts a price  $T_{BF}$ ,  $T_{BF} > c_T^M$  and  $T_{FB} > c_T^F$ . However, when they negotiate jointly to maximise  $p_A + p_F + p_B$ , they choose  $T_{BF} < c_T^M$  and  $T_{FB} > c_T^F$ .*

PROOF: Observe that,

$$\begin{aligned} \left. \frac{\partial p_B}{\partial T_{BF}} \right|_{T_{BF}=c_T^M, T_{FB}=c_T^F} &= \frac{an - c_1 - c_o^F - c_T^M}{12b(1+n)} > 0 \\ \left. \frac{\partial (p_A + p_F)}{\partial T_{FB}} \right|_{T_{BF}=c_T^M, T_{FB}=c_T^F} &= -\frac{(2+n)v'(c_1 + c_T^F + c_o^M)}{3(1+n)} > 0 \\ \left. \frac{\partial (p_B + p_A + p_F)}{\partial T_{BF}} \right|_{T_{BF}=c_T^M, T_{FB}=c_T^F} &= -\frac{c_1 + c_o^F + c_T^M}{12b(1+n)} < 0 \end{aligned}$$

$$\frac{\partial(\mathbf{p}_B + \mathbf{p}_A + \mathbf{p}_F)}{\partial T_{FB}} \Big|_{T_{BF}=c_T^M, T_{FB}=c_T^F} = -\frac{v'(c_1 + c_T^F + c_O^M)}{1+n} > 0.$$

Intuitively, an increase in either termination charge imposes a negative effect on a rival network's profits. Hence, when those prices are chosen independently, that effect is not internalised and charges are relatively high. When they are chosen as part of negotiations they are chosen to maximise joint profits. As high levels of  $T_{BF}$  serve to strengthen price competition, this is set below marginal termination cost to weaken such competition. On the other hand, positive termination profits received by the fixed network weakens price competition. Hence,  $T_{FB}$  is chosen above marginal termination cost. In the end, this results in a socially inefficient outcome as  $\mathbf{a} > \frac{1}{2}$  and both mobile to fixed and fixed to mobile call prices do not reflect marginal cost.

## 5.11 Regulation

We are now in a position to consider the implications of alternative regulatory options in an environment where there is mobile network competition.

### 5.11.1 Bargaining between the fixed and mobile networks

We have already examined the implications of bargaining between fixed and mobile networks. When there is no integration, all termination charges are set equal to the marginal termination costs of the respective networks. However, when there is some vertical integration, the negotiated outcome may involve fixed network termination charges above and mobile network termination charges below marginal termination cost. This is because the networks are able to use the termination charges to influence the strength of price competition among the respective mobile networks. Specifically, negotiated outcomes will be agreed upon that soften this competition. This leads to an agreement that the independent mobile network has higher 'costs'

than the integrated one. As a consequence, the integrated mobile network has too large a market share.

Nonetheless, overall bargaining reduces or eliminates double marginalisation issues and may lead to substantial reductions in inter-network call prices.

### 5.11.2 Carrier identification

When fixed line consumers can distinguish between the mobile networks they are calling and have knowledge of any price differentials, the termination charges and fixed to mobile call prices are the same as the fixed market share case. In this case, there is no direct externality from changing termination charges. Instead, mobile networks have an incentive to maximise their profits from their termination service as this lowers their effective costs from attracting another mobile customer.

$$p_A = \frac{1+n+s(T_{AB}-c_T^M)q_{BA}-s\Lambda}{4(1+n)s} \left( 1+2s \frac{n((T_{AF}-c_T^M)q_{FA}-(T_{BF}-c_T^M)q_{FB})+\Omega+\frac{1}{2}\Lambda}{2s(T_{AB}+T_{BA}-2c_T^M)q_{BA}+3(1+n-s\Lambda)} \right)^2 \quad (5.9)$$

As can easily be seen from the above equation, profits still depend on relative profits from their termination services but a given mobile network's termination charge only influences its own termination revenues.

When one mobile network is integrated with the fixed network, the termination charge set by the non-integrated network will still choose its termination charge to maximise its termination profits. However, fixed to mobile call prices on the integrated carrier will be reduced as they eliminate the double marginalisation problem. A similar outcome could be achieved if mobile and fixed networks negotiate with one another.

### 5.11.3 Direct setting of termination charges

The issues regarding the direct setting of termination charges are essentially the same as the fixed mobile market shares case. By setting lower termination charges, inter-network call prices will fall. Here, however, the setting of such charges will impact upon mobile subscription charges.

In particular, any reduction in termination charges that reduces revenue from termination services will increase mobile subscription charges. In our model, this will be welfare improving as the total number of mobile customers is fixed. If this were not the case, then an increase in mobile subscription charges may reduce total mobile phone adoption by consumers. The welfare implications of such interactions are complex and it is unclear what the precise welfare effects would be.

Nonetheless, what this suggests is that the regulator has to be more imaginative in determining a pricing methodology. For example, by setting termination charges equal to zero, fixed to mobile prices would fall. To offset the potential increase in subscription rates to mobile users, the termination charge could be substituted for a flat fee paid by the fixed network to the mobile network. What this fee would be designed to do would be to mimic the outcome that would result if termination revenues were high. That is, if a mobile network attracted a customer, this should be rewarded. While if a mobile network were to lose a customer this could be punished. Mobile networks would then only receive a fixed fee if they had a net gain in subscribers. Moreover, this fee would relate to half the expected termination profits that the network would receive from those customers. Such a scheme would allow fixed to mobile prices to stay low (as it would not influence the marginal cost faced by the fixed network) but would allow for competition among mobile networks to be intensified.

## 6 Fixed Network Competition

Some of the competitive difficulties that arise from the setting of termination charges arise from the monopoly position of the fixed network. If this were more competitive some of the interactions may change.

When setting the price of fixed to mobile calls, the fixed network sets a monopoly price – whether consumers can effectively observe price differentials or not. If there were competition in the setting of this price, it would be set closer to marginal cost (and perhaps equal to marginal cost if non-linear pricing was possible). However, this marginal cost still includes the termination charge as set by the mobile networks and they are still driven to an equilibrium outcome that reduces the quantity of fixed to mobile calls to zero. It is only where consumers are not ignorant of the mobile network they are calling that the prices of fixed to mobile calls may actually fall as a result of fixed network competition.

Above, in the absence of fixed network competition, we found that the price of mobile to fixed calls would equal marginal cost and termination charges would be set to induce monopoly pricing on this service. This will still be the case if mobile consumers can distinguish between the fixed networks they are calling. However, if those consumers are ignorant of these differences, then the same equilibrium forces that arose for fixed to mobile calls will drive traffic to zero. In this respect, fixed network competition may ultimately induce higher, not lower, prices for mobile to fixed calls. Once again, however, a negotiated outcome is likely to induce more competitive pricing.

Finally, suppose that two integrated fixed-mobile networks competed against one another. Then, in many respects, the setting of termination charges between them would result in the same outcomes as analysed in the literature

on network competition.<sup>20</sup> Specifically, termination charges could be used to raise prices by softening competition for subscribers.

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<sup>20</sup> See Armstrong (1998), Laffont, Rey and Tirole (1998a, 1998b) and Carter and Wright (1999).

## 7 Future Directions

This paper has analysed the determinants of termination charges for calls to mobile networks. Because of the number of prices involved and the potential complexity of strategic interactions we have kept the assumptions relatively minimal and symmetric. In particular, we have assumed considerable knowledge of consumer demand, simple horizontal product differentiation, and equivalent mobile network technologies. Nonetheless, we believe that such assumptions are not restrictive and relaxing them would not alter our key results.

That said, there are issues that were raised by our research that are still unresolved. First, efficient termination pricing is possible and can be facilitated by non-linear pricing such as two-part tariffs. While we know that usage charges in such pricing schemes should reflect marginal costs the issue of fixed charges is more difficult. Current research suggests that these should be structured to induce optimal investment incentives.<sup>21</sup> However, the analysis here was essentially static and, as such, not able to address such issues.

Indeed, introducing dynamic analysis into the model would allow other issues to be addressed. In particular, we have assumed that mobile users and fixed line users are independent. This neglects the important issue of the adoption of mobile services by consumers and their interaction with consumers who also consume fixed line services. It also neglects the role for new wireless technologies and their impact on mobile competition.

Finally, and related to this, our model did not consider entry and its effects. In particular, we did not consider explicitly the role of termination

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<sup>21</sup> See Gans and Williams (1999a, 1999b) and Gans (1999) for a discussion of regulated pricing and investment incentives.

charging in altering the incentives of entrants. This too remains a fruitful area for future research.

In concluding, it should be noted that our analysis here is not at all specific to mobile network issues. Indeed, to the extent that consumers have difficulty distinguishing among competing carriers (a problem exacerbated by the steady introduction of local number portability), then these considerations would apply to interactions between many telecommunications networks including fixed line networks and data communication services. Thus, we expect that the results on termination presented here would also apply to many other inter-network regulatory situations in telecommunications.

## 8 Appendix

Here we list the equilibrium values of  $F_A$  and  $F_B$  that arise in stage 2; given termination charges set in stage 1.

$F_A =$

$f +$

$$\begin{aligned}
& | 3 + 6n + 3n^2 - 4ns^2 c_T^2 H q_{AB} q_{FA} + q_{BA} q_{FB} L - 4ns q_{FA} T_{AF} - 4n^2 s q_{FA} T_{AF} + 2s q_{AB} T_{BA} + \\
& 2ns q_{AB} T_{BA} - 4ns^2 q_{AB} q_{FA} T_{AF} T_{BA} - 2ns q_{FB} T_{BF} - 2n^2 s q_{FB} T_{BF} - 12sv@c_1 + c_0 + c_T D - \\
& 12ns v@c_1 + c_0 + c_T D + 8ns^2 q_{FA} T_{AF} v@c_1 + c_0 + c_T D - 4s^2 q_{AB} T_{BA} v@c_1 + c_0 + c_T D + \\
& 4ns^2 q_{FB} T_{BF} v@c_1 + c_0 + c_T D + 12s^2 v@c_1 + c_0 + c_T D^2 + 5sv@c_1 + c_0 + T_{AB} D + \\
& 5ns v@c_1 + c_0 + T_{AB} D - 4ns^2 q_{FA} T_{AF} v@c_1 + c_0 + T_{AB} D + 2s^2 q_{AB} T_{BA} v@c_1 + c_0 + T_{AB} D - \\
& 2ns^2 q_{FB} T_{BF} v@c_1 + c_0 + T_{AB} D - 10s^2 v@c_1 + c_0 + c_T D v@c_1 + c_0 + T_{AB} D + 2s^2 v@c_1 + c_0 + T_{AB} D^2 + \\
& 7sv@c_1 + c_0 + T_{BA} D + 7ns v@c_1 + c_0 + T_{BA} D - 4ns^2 q_{FA} T_{AF} v@c_1 + c_0 + T_{BA} D + \\
& 2s^2 q_{AB} T_{BA} v@c_1 + c_0 + T_{BA} D - 2ns^2 q_{FB} T_{BF} v@c_1 + c_0 + T_{BA} D - 14s^2 v@c_1 + c_0 + c_T D v@c_1 + c_0 + T_{BA} D + \\
& 6s^2 v@c_1 + c_0 + T_{AB} D v@c_1 + c_0 + T_{BA} D + 4s^2 v@c_1 + c_0 + T_{BA} D^2 + 2ns v@c_1 + c_0 + T_{FA} D + \\
& 2n^2 sv@c_1 + c_0 + T_{BA} D - 4ns^2 v@c_1 + c_0 + c_T D v@c_1 + c_0 + T_{FA} D + \\
& 2ns^2 v@c_1 + c_0 + T_{AB} D v@c_1 + c_0 + T_{FA} D + 2ns^2 v@c_1 + c_0 + T_{BA} D v@c_1 + c_0 + T_{FA} D - \\
& 2ns v@c_1 + c_0 + T_{FB} D - 2n^2 sv@c_1 + c_0 + T_{FB} D + 4ns^2 v@c_1 + c_0 + c_T D v@c_1 + c_0 + T_{FB} D - \\
& 2ns^2 v@c_1 + c_0 + T_{AB} D v@c_1 + c_0 + T_{FB} D - 2ns^2 v@c_1 + c_0 + T_{BA} D v@c_1 + c_0 + T_{FB} D + \\
& 2sq_{BA} T_{AB} H_1 + n - 2ns q_{FB} T_{BF} - 2sv@c_1 + c_0 + c_T D + 2sv@c_1 + c_0 + T_{BA} D + 2ns v@c_1 + c_0 + T_{FA} D - \\
& 2ns v@c_1 + c_0 + T_{FB} D L + \\
& 2sc_T \\
& Hq_{AB} H - 1 - n + 2ns q_{FA} H T_{AF} + T_{BA} L + 2sv@c_1 + c_0 + c_T D - sv@c_1 + c_0 + T_{AB} D - sv@c_1 + c_0 + T_{BA} D L + \\
& n H 2 q_{FA} + q_{FB} L H_1 + n - 2sv@c_1 + c_0 + c_T D + sv@c_1 + c_0 + T_{AB} D + sv@c_1 + c_0 + T_{BA} D L + \\
& q_{BA} H - 1 - n + 2ns q_{FB} H T_{AB} + T_{BF} L + 2sv@c_1 + c_0 + c_T D - 2sv@c_1 + c_0 + T_{BA} D - \\
& 2ns v@c_1 + c_0 + T_{FA} D + 2ns v@c_1 + c_0 + T_{FB} D L L M \bullet \\
& H_2 H_1 + n L s H_3 + 3n - 2sc_T H q_{AB} + q_{BA} L + 2sq_{BA} T_{AB} + 2sq_{AB} T_{BA} - 6sv@c_1 + c_0 + c_T D + \\
& 3sv@c_1 + c_0 + T_{AB} D + 3sv@c_1 + c_0 + T_{BA} D L L
\end{aligned}$$

$F_B =$ 
 $f +$ 

$$\begin{aligned}
& | 3 + 6n + 3n^2 - 2s c_T q_{AB} - 2ns c_T q_{AB} - 2s c_T q_{BA} - 2ns c_T q_{BA} - 4ns^2 c_T^2 H_{q_{AB} q_{FA}} + q_{BA} q_{FB} L + \\
& 2s^2 q_{BA} T_{AB} + 2ns q_{BA} T_{AB} - 2ns q_{FA} T_{AF} - 2n^2 s q_{FA} T_{AF} + 2s q_{AB} T_{BA} + 2ns q_{AB} T_{BA} - \\
& 4ns^2 q_{AB} q_{FA} T_{AF} T_{BA} + 4ns^2 c_T q_{AB} q_{FA} H_{T_{AF} + T_{BA} L} - 4ns q_{FB} T_{BF} - 4n^2 s q_{FB} T_{BF} - \\
& 4ns^2 q_{BA} q_{FB} T_{AB} T_{BF} + 4ns^2 c_T q_{BA} q_{FB} H_{T_{AB} + T_{BF} L} - 12sv@c_1 + c_0 + c_T D - 12ns v@c_1 + c_0 + c_T D + \\
& 4s^2 c_T q_{AB} v@c_1 + c_0 + c_T D + 4s^2 c_T q_{BA} v@c_1 + c_0 + c_T D - 4s^2 q_{BA} T_{AB} v@c_1 + c_0 + c_T D + \\
& 4ns^2 q_{FA} T_{AF} v@c_1 + c_0 + c_T D - 4s^2 q_{AB} T_{BA} v@c_1 + c_0 + c_T D + 8ns^2 q_{FB} T_{BF} v@c_1 + c_0 + c_T D + \\
& 12s^2 v@c_1 + c_0 + c_T D^2 + 7sv@c_1 + c_0 + T_{AB} D + 7ns v@c_1 + c_0 + T_{AB} D - 4s^2 c_T q_{AB} v@c_1 + c_0 + T_{AB} D - \\
& 2s^2 c_T q_{BA} v@c_1 + c_0 + T_{AB} D + 2s^2 q_{BA} T_{AB} v@c_1 + c_0 + T_{AB} D - 2ns^2 q_{FA} T_{AF} v@c_1 + c_0 + T_{AB} D + \\
& 4s^2 q_{AB} T_{BA} v@c_1 + c_0 + T_{AB} D - 4ns^2 q_{FB} T_{BF} v@c_1 + c_0 + T_{AB} D - 14s^2 v@c_1 + c_0 + c_T D v@c_1 + c_0 + T_{AB} D + \\
& 4s^2 v@c_1 + c_0 + T_{AB} D^2 + 5sv@c_1 + c_0 + T_{BA} D + 5ns v@c_1 + c_0 + T_{BA} D - 2s^2 c_T q_{BA} v@c_1 + c_0 + T_{BA} D + \\
& 2s^2 q_{BA} T_{AB} v@c_1 + c_0 + T_{BA} D - 2ns^2 q_{FA} T_{AF} v@c_1 + c_0 + T_{BA} D - 4ns^2 q_{FB} T_{BF} v@c_1 + c_0 + T_{BA} D - \\
& 10s^2 v@c_1 + c_0 + c_T D v@c_1 + c_0 + T_{BA} D + 6s^2 v@c_1 + c_0 + T_{AB} D v@c_1 + c_0 + T_{BA} D + \\
& 2s^2 v@c_1 + c_0 + T_{BA} D^2 + \\
& 2ns c_T H_{q_{BA}} + 2q_{FB} L H_1 + n - 2sv@c_1 + c_0 + c_T D + sv@c_1 + c_0 + T_{AB} D + sv@c_1 + c_0 + T_{BA} D L - \\
& 2ns v@c_1 + c_0 + T_{FA} D - 2n^2 s v@c_1 + c_0 + T_{FA} D + 4ns^2 c_T q_{AB} v@c_1 + c_0 + T_{FA} D - \\
& 4ns^2 q_{AB} T_{BA} v@c_1 + c_0 + T_{FA} D + 4ns^2 v@c_1 + c_0 + c_T D v@c_1 + c_0 + T_{FA} D - \\
& 2ns^2 v@c_1 + c_0 + T_{AB} D v@c_1 + c_0 + T_{FA} D - 2ns^2 v@c_1 + c_0 + T_{BA} D v@c_1 + c_0 + T_{FA} D + \\
& 2ns v@c_1 + c_0 + T_{FB} D + 2n^2 s v@c_1 + c_0 + T_{FB} D - 4ns^2 c_T q_{AB} v@c_1 + c_0 + T_{FB} D + \\
& 4ns^2 q_{AB} T_{BA} v@c_1 + c_0 + T_{FB} D - 4ns^2 v@c_1 + c_0 + c_T D v@c_1 + c_0 + T_{FB} D + \\
& 2ns^2 v@c_1 + c_0 + T_{AB} D v@c_1 + c_0 + T_{FB} D + 2ns^2 v@c_1 + c_0 + T_{BA} D v@c_1 + c_0 + T_{FB} D M \bullet \\
& H_2 H_1 + nL s H_3 + 3n - 2s c_T H_{q_{AB}} + q_{BA} L + 2s q_{BA} T_{AB} + 2s q_{AB} T_{BA} - 6sv@c_1 + c_0 + c_T D + \\
& 3sv@c_1 + c_0 + T_{AB} D + 3sv@c_1 + c_0 + T_{BA} D L L
\end{aligned}$$

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