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Stefan Buehler* and Armin Schmutzler**

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ABSTRACT: We aim to clarify the role of access charges under two-way network competition, employing a reduced-form approach. Retaining the key features of specific network competition models but imposing less structure, we analyze the impact of changes in access charges on linear and non-linear retail prices. We derive sufficient conditions for usage fees to be increasing (and subscriber charges to be decreasing) in access charges. These conditions are shown to be satisfied only under rather restrictive assumptions on the demand for calls, suggesting that implementing collusion by inflating access charges is likely to be non-feasible.

Keywords: network competition, two-way access, collusion, non-linear retail prices.

JEL: D43, L43.

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1 Introduction

The problem of setting the ‘right’ access charge in the telecommunications industry has been analyzed extensively. There appears to be a broad consensus that access charges need to be regulated in the case of *one-way access*, where the incumbent monopolist controls an essential facility (e.g. the local fixed network) and competes with entrants in related markets (e.g. long distance services).¹ In contrast, the debate on the problem of *two-way access* is far from settled. This problem arises in more mature industries, where the incumbent faces competitors that have deployed their own network facilities, so that mutual access is required to place calls to all subscribers. In this setting, it is less than obvious that access charges should be regulated, as competition for end users may, at least in principle, discipline both access and retail prices.

In two seminal papers, Armstrong (1998) and Laffont, Rey and Tirole (1998a)—henceforth abbreviated by ALRT—have put forward a formal framework for analyzing the role of access charges under two-way network competition. One of the key findings of these papers is that the access charge may serve as an *instrument of collusion* when networks compete in linear retail prices. To some extent, this result is intuitive: Increasing the access charge is equivalent to increasing the competitor’s perceived marginal cost, thereby softening competition in the retail market. This “raise-each-other’s-cost effect” (Laffont and Tirole 2000, 190) might suggest that access charges should also be regulated in the case of two-way network competition.²

Based on the ALRT framework, a number of contributions surveyed in Laffont and Tirole (2000), Armstrong (2002), Vogelsang (2003), and Peitz et al. (2004) have emphasized that the collusive role of access charges is less robust than one might think.³ In particular, if retail tariffs are non-linear

¹See e.g. Laffont and Tirole (2000, chapters 3 and 4) for a survey of the relevant issues.

²Note that the usage of the word “collusion” in this context is debatable, as it neither refers to an explicit agreement nor to implicit collusion in a repeated game sense: Higher access charges merely move the industry to an equilibrium with both higher retail prices and profits.

³See, e.g., Gans and King (2001), Schiff (2002), Carter and Wright (2003), Dessein (2003, 2004), and Armstrong (2004).

and/or customers are heterogenous, it is far from obvious that usage fees are increasing in access charges (Dessein 2003). Thus, even when firms are free to set access prices themselves, they do not necessarily price above marginal costs.

In the present paper, we aim to clarify the role of access charges under network competition with two-way access, using a *reduced-form* approach. Because we focus on comparative statics issues, we need a less restrictive structure than usual in this literature. We retain the following key features of the various models considered in the literature that are motivated by the real world:

- (i) Facing access charges, firms set their retail prices;
- (ii) Facing retail prices, consumers take their subscription decisions;
- (iii) The calling pattern, that is, the number of internal and external calls initiated in each network, is a function of both the size of the two networks and the retail price charged by that network.

We do not, however, impose some of the simplifying assumptions that are routinely applied in the literature. Instead, we start out more generally and then discuss to what extent assumptions familiar from the literature bias the results. Our findings support the view that the collusive role of access charges is generally not very robust. We argue that this non-robustness is associated with the underlying economics of two-way network competition rather than the various simplifying assumptions made for studying specific models.

Below, we first consider the case of *linear* retail prices. For this setting, we confirm that (i) even in cases where higher access charges do increase equilibrium retail prices, the raise-each-other's cost intuition is incomplete (for reasons to be discussed below); (ii) it is not evident that higher access charges increase retail prices, so that collusion based on inflated access charges might not be a concern to begin with. Put differently, we show that it is neither clear that higher access prices shift out reaction curves in the retail price game, nor that reaction curves are upward sloping. We then demonstrate that the standard assumptions of full coverage networks and

balanced calling patterns tend to support the collusive role of access charges, without making it robust. We also show that retail prices definitely increase under either of the following (rather extreme) assumptions: (i) networks are symmetric; (ii) the total number of subscribers and the number of subscribers to each network are fixed.

We then move on to *non-linear* retail prices. Laffont et al. (1998a) and Dessein (2003) argue that if networks compete in two-part retail tariffs, an increase of the access charge still increases the variable component of the two-part tariff, but also lowers the fixed component so as to just offset any effects on profits. Again, we aim to clarify the intuition behind this result and its limitations using our reduced-form framework. To this end, we formulate a general comparative statics result that leads to the desired conclusion. We then show that the required conditions are fairly intuitive, but may well be violated in reasonable cases.

The remainder of the paper is organized as follows. Section 2 introduces our reduced-form model for linear retail prices. Section 3 discusses how two simplifying assumptions familiar from the literature, full coverage networks and balanced calling patterns, affect the comparative statics with respect to access charges. Section 4 extends the analysis to non-linear retail tariffs. Section 5 discusses further extensions and concludes.

2 Linear Retail Prices

In this section, we introduce a reduced-form model of two-way network competition with linear retail prices, imposing very little structure on the demand for calls within and across networks. We consider more specific models familiar from the literature in the next section.

2.1 Assumptions

Consider a reduced-form model of two-way network competition with the following structural elements:

- *Cost structure:* There are two networks with identical cost structure. There is a marginal cost c_0 per call at the originating and terminating

end of a call and c_1 in between. Total marginal cost is thus given by $c \equiv 2c_0 + c_1$, as in Laffont et al. (1998a).⁴ There is a fixed cost K_i of operating network i .

- *Demand structure:* The networks are differentiated and compete in retail prices. We abstract both from the type of network differentiation and the details of the consumers' subscription decisions and simply assume that there is a well-defined demand function for each of the various types of calls. More specifically, let $i, j = 1, 2, j \neq i$. Then $D_{ii}(p_i, p_j)$ denotes the demand for calls initiated and terminated in network i . Similarly, $D_{ij}(p_i, p_j)$ denotes the demand for calls initiated in network i and terminated in network j . Suppose that each of these demand functions is twice continuously differentiable.

The profit function of network i is thus given by

$$\begin{aligned} \pi_i(p_i, p_j) = & (p_i - c) D_{ii}(p_i, p_j) + (p_i - a_j - c_1 - c_0) D_{ij}(p_i, p_j) \\ & + (a_i - c_0) D_{ji}(p_i, p_j) - K_i, \end{aligned} \quad (1)$$

where a_i and a_j denote the access charges set by network i and j , respectively, i.e., the prices to be paid for terminating a call initiated in the competing network. Even though we shall formulate our main comparative statics result in terms of the reduced-form demand functions D_{ii} and D_{ij} , it will be useful to decompose these functions into (i) the number of subscribers, and (ii) the number of calls initiated by each subscriber. We therefore introduce the following notation:

Notation 1 (demand with linear tariffs) For $i, j = 1, 2, i \neq j$, we let $n_i(p_i, p_j)$ denote the **number of subscribers** to network i . Further, let $\hat{m}_{ii}(p_i, p_j) \equiv m_{ii}(n_i(p_i, p_j), n_j(p_i, p_j), p_i)$ denote the **number of internal calls per subscriber** and $\hat{m}_{ij}(p_i, p_j) \equiv m_{ij}(n_i(p_i, p_j), n_j(p_i, p_j), p_i)$ the **number of external calls per subscriber to network i** . Then, the demand

⁴In our framework, it would be straightforward to incorporate asymmetric marginal costs. However, doing so would make the notation more cumbersome, without changing the results.

functions can be written as

$$\begin{aligned} D_{ii}(p_i, p_j) &\equiv n_i(p_i, p_j) \cdot \widehat{m}_{ii}(p_i, p_j), \\ D_{ij}(p_i, p_j) &\equiv n_i(p_i, p_j) \cdot \widehat{m}_{ij}(p_i, p_j). \end{aligned}$$

Understanding the demand functions D_{ii} and D_{ij} thus amounts to understanding the relation between retail prices and (a) the individuals' subscription decisions (represented by n_i and n_j), and (b) the number of calls per subscriber (\widehat{m}_{ii} and \widehat{m}_{ij} , respectively). Note that a subscriber's demand \widehat{m}_{ii} for internal calls depends not only on the price p_i per call, but also on the number of subscribers to each network: A customer of a large network i will place more internal calls than a customer of a small network. Hence, indirectly \widehat{m}_{ii} depends on p_j as well as p_i , since p_j affects the numbers of customers in both networks and thus the calling pattern of each subscriber to network i . As a result, the total effect of a change in the retail price p_i on the number of internal calls per subscriber, \widehat{m}_{ii} , is given by

$$\frac{\partial \widehat{m}_{ii}}{\partial p_i} = \frac{\partial m_{ii}}{\partial p_i} + \frac{\partial m_{ii}}{\partial n_i} \frac{\partial n_i}{\partial p_i} + \frac{\partial m_{ii}}{\partial n_j} \frac{\partial n_j}{\partial p_i}, \quad (2)$$

and similarly for the effect on external calls, $\partial \widehat{m}_{ij} / \partial p_i$. The total effect of a change in the competitor's retail price p_j on the number of internal calls per subscriber is given by

$$\frac{\partial \widehat{m}_{ij}}{\partial p_j} = \frac{\partial m_{ij}}{\partial n_i} \frac{\partial n_i}{\partial p_j} + \frac{\partial m_{ij}}{\partial n_j} \frac{\partial n_j}{\partial p_j}, \quad (3)$$

and similarly for $\partial \widehat{m}_{ii} / \partial p_j$.

We maintain the following assumptions on the components of demand.

Assumption 1 (demand properties) *The components of demand satisfy the following properties:*

- (i) n_i, m_{ii} and m_{ij} are differentiable functions.
- (ii) $\partial n_i / \partial p_i < 0$; $\partial n_i / \partial p_j > 0$.
- (iii) $\partial m_{ii} / \partial n_i > 0$; $\partial m_{ii} / \partial n_j < 0$.

(iv) $\partial m_{ii}/\partial p_i < 0$; $\partial m_{ii}/\partial p_j > 0$.

(v) $\partial m_{ij}/\partial p_i < 0$.

Assumption (i) is made for notational convenience only. The remaining assumptions are plausible properties of the demand components. Assumption (ii), for instance, reflects the substitution effect associated with an increase of a network's retail price.⁵ Property (iii) formalizes the notion that an increase in the size of a network should increase (decrease) the number of internal calls per subscriber in this (the competitor's) network. Property (iv) reflects substitution effects for internal calls. Finally, property (v) states that the demand for external calls per subscriber is downward sloping.

Note that Assumption 1 implies

$$\frac{\partial \widehat{m}_{ii}}{\partial p_i} < 0 \quad \text{and} \quad \frac{\partial \widehat{m}_{ii}}{\partial p_j} > 0,$$

but no corresponding statement on $\partial \widehat{m}_{ij}/\partial p_i$ and $\partial \widehat{m}_{ij}/\partial p_j$. We illustrate the ambiguity for $\partial \widehat{m}_{ij}/\partial p_j$ using (3). By Assumption 1(ii), $\partial n_i/\partial p_j > 0$ and $\partial n_j/\partial p_j < 0$, whereas the signs of the remaining partials are not determined. Under the reasonable condition that the number of external calls per subscriber is increasing in the size of both networks ($\partial m_{ij}/\partial n_i > 0$, $\partial m_{ij}/\partial n_j > 0$)—more subscribers to network i are likely to place more calls to network j , and more subscribers to network j make it more likely that subscribers want to place calls to network j —the sign of $\partial \widehat{m}_{ij}/\partial p_j$ is ambiguous.⁶

Our next assumption is made for convenience and requires that the components of demand are separable.

Assumption 2 (separability) *The demand components are separable in retail prices, i.e.*

$$\frac{\partial^2 n_i}{\partial p_i \partial p_j} = 0, \quad \frac{\partial \widehat{m}_{ij}}{\partial p_i \partial p_j} = 0, \quad \text{and} \quad \frac{\partial_{ij}^2 \widehat{m}_{ij}}{\partial p_i \partial p_j} = 0.$$

⁵In the absence of a full coverage assumption (see Section 3.1 for details), the second part of this assumption is not quite as natural: In principle, because an increase in p_j reduces n_j , it might also make subscription to network i less attractive.

⁶The arguments for $\partial \widehat{m}_{ij}/\partial p_i$ are analogous.

Note that Assumption 2 does not imply separability of the demand functions D_{ii} and D_{ij} themselves.⁷

Finally, since we want to focus on comparative statics, we need to assume that an equilibrium exists. It is well-known from specific models of two-way network competition that the *existence of equilibrium* is not assured, especially if access charges and the substitutability of networks are high.

2.2 Comparative Statics

We now carry out comparative statics with respect to access prices. The analytical framework put forward by ALRT suggests that by “raising each others’ cost”, access charges may serve as collusive devices. Very roughly, the following intuition might appear plausible: By making access to its network more costly, both firms shift out the competitor’s reaction curve. If retail prices are strategic complements, indirect effects reinforce the direct effects. Though this story bears a grain of truth (Laffont and Tirole 2000, 189), it is both misleading and incomplete. First, it ignores the role of access charges as a means of generating revenue. Second, it neglects some special characteristics of network competition suggesting that retail prices are strategic *substitutes* in the demand function rather than complements. Once these issues are taken into account, it is neither obvious that higher access charges shift out reaction curves nor that indirect effects work into the ‘right direction’.

Nevertheless, we start with a simple result that formalizes the intuitive argument for collusion laid out above by giving sufficient conditions for equilibrium retail prices to be increasing in access charges.⁸

Proposition 1 (linear tariffs) *Suppose that for $i, j = 1, 2, i \neq j$, retail*

⁷For instance, under Assumption 2, we have

$$\frac{\partial^2 D_{ii}}{\partial p_i \partial p_j} = \frac{\partial n_i}{\partial p_j} \frac{\partial \hat{m}_{ii}}{\partial p_i} + \frac{\partial n_i}{\partial p_i} \frac{\partial \hat{m}_{ii}}{\partial p_j}.$$

⁸The proposition is formulated for a unique equilibrium of the price game. It generalizes to equilibrium sets as in Milgrom and Roberts (1990).

prices are strategic complements, i.e.,

$$\frac{\partial^2 \pi_i}{\partial p_i \partial p_j} = \frac{\partial D_{ii}}{\partial p_j} + \frac{\partial D_{ij}}{\partial p_j} + (p_i - c) \frac{\partial^2 D_{ii}}{\partial p_i \partial p_j} + (p_i - a_j - c_0) \frac{\partial^2 D_{ij}}{\partial p_i \partial p_j} + (a_j - c_0) \frac{\partial^2 D_{ji}}{\partial p_i \partial p_j} \geq 0. \quad (4)$$

(i) *If, in addition to (4), reaction curves shift outwards, i.e.,*

$$\frac{\partial^2 \pi_i}{\partial p_i \partial a_i} = \frac{\partial D_{ji}}{\partial p_i} \geq 0 \quad \text{and} \quad \frac{\partial^2 \pi_j}{\partial p_j \partial a_i} = -\frac{\partial D_{ji}}{\partial p_j} > 0, \quad (5)$$

then the equilibrium of the price game is increasing in a_i .

(ii) *If, in addition to (4) both firms face the same access price a and*

$$\frac{\partial^2 \pi_i}{\partial p_i \partial a} = \frac{\partial D_{ji}}{\partial p_i} - \frac{\partial D_{ij}}{\partial p_i} > 0, \quad (6)$$

then the equilibrium of the price game is increasing in a .

Proof. Results (i) and (ii) follow immediately from Milgrom and Roberts (1990, Th. 5): Condition (4) guarantees that the game is supermodular; conditions (5) and (6) make sure that it satisfies increasing differences in $(p_i, p_j; \theta)$, with $\theta = a_i$ or a , respectively. ■

Result (i) guarantees that both retail prices increase when *either* firm raises its access charge. The result is thus directly relevant for cases where firms themselves choose access charges—cooperatively or non-cooperatively—and compete in the retail market, highlighting the collusive role of access charges. Result (ii) concerns the effects of a simultaneous increase in *both* access prices. It pertains to the important case where either the regulatory regime requires access charges to be reciprocal (as, e.g., in the U.S.) or the network operators negotiate symmetric access charges.

We now explore whether the sufficient conditions for a collusive role of access charges ((4), (5) and (6)) are likely to be satisfied.

2.3 Are Retail Prices Strategic Complements?

In standard models of oligopolistic price competition, there is a natural force towards strategic complementarity of pricing decisions: If the competitors

produce substitutes, a higher price of firm j increases the demand of firm i . Thus, a price increase of firm i becomes more attractive as it applies to a greater number of inframarginal consumption units. The strategic complementarity of pricing decisions breaks down only if the demand function itself has negative cross-partials, that is, if prices are strategic substitutes in the demand function, and this effect is sufficiently strong.

For network competition models with two-sided access, there are two natural reasons why strategic complementarity in retail prices may be violated, so that $\partial^2\pi_i/\partial p_i\partial p_j < 0$ at least for some prices:

- (i) The products offered by different networks are not necessarily substitutes, i.e. the demand for calls offered by network i does not necessarily increase with an increase in network j 's retail price.
- (ii) The retail prices may be strategic substitutes in the demand functions, i.e. the cross-partials of the demand functions may be negative.

First consider reason (i). Observe that by Assumption 1

$$\frac{\partial D_{ii}}{\partial p_j} = m_{ii}\frac{\partial n_i}{\partial p_j} + n_i\frac{\partial \hat{m}_{ii}}{\partial p_j} > 0, \quad (7)$$

i.e., the demand for internal calls is unambiguously increasing in the competitor's retail price. The effect on the demand for external calls,

$$\frac{\partial D_{ij}}{\partial p_j} = m_{ij}\frac{\partial n_i}{\partial p_j} + n_i\frac{\partial \hat{m}_{ij}}{\partial p_j}, \quad (8)$$

however, is less clear: The first term is positive by Assumption 1(ii), but the second term has an ambiguous sign, so that it is not guaranteed that $\partial D_{ij}/\partial p_j > 0$. Intuitively, higher competitor prices might have a negative effect on the size of the competitor's network and thereby reduce the number of outgoing calls. Nevertheless, (7) and (8) together suggest that the total effect on demand ($\partial D_{ii}/\partial p_j + \partial D_{ij}/\partial p_j$) is likely to be positive, supporting strategic complementarity in retail prices.

Consider now reason (ii). On the one hand, a familiar force towards strategic complementarity is present: As $\partial D_{ii}/\partial p_j > 0$, a higher competitor price increases own demand for internal calls, which makes a price increase

more valuable. On the other hand, it is important to note that there is a natural force towards a negative cross-partial for the demand function D_{ii} , in spite of our separability assumption on the underlying demand components. Using Assumptions 1 and 2, as well as the decomposition given in (7), we obtain

$$\frac{\partial^2 D_{ii}}{\partial p_i \partial p_j} = \frac{\partial n_i}{\partial p_j} \frac{\partial \widehat{m}_{ii}}{\partial p_i} + \frac{\partial n_i}{\partial p_i} \frac{\partial \widehat{m}_{ii}}{\partial p_j} < 0,$$

which is unambiguously negative. Intuitively, an *increase* in the competitor's retail price increases both the number of own subscribers and the volume of internal calls per subscriber. The same is true for a *reduction* in own retail price. Thus, with a higher competitor price, the positive effect of an own price reduction on demand per subscriber applies to a greater customer base, so that the demand-enhancing effect of the price reduction is more pronounced. Similarly, the positive effect on the subscriber number applies to a greater call volume per subscriber.

The argument for the remaining cross partials is again less clear-cut. For instance, we obtain

$$\frac{\partial^2 D_{ij}}{\partial p_i \partial p_j} = \frac{\partial n_i}{\partial p_j} \frac{\partial \widehat{m}_{ij}}{\partial p_i} + \frac{\partial n_i}{\partial p_i} \frac{\partial \widehat{m}_{ij}}{\partial p_j},$$

which has an ambiguous sign: We know that $\partial n_i / \partial p_j > 0$, $\partial n_i / \partial p_i < 0$ by Assumption 1(ii), but $\partial \widehat{m}_{ij} / \partial p_i$ and $\partial \widehat{m}_{ij} / \partial p_j$ have ambiguous signs. A similar result holds for $\partial^2 D_{ji} / \partial p_i \partial p_j$.

Summing up, our reduced-form model of network competition with linear retail prices incorporates the standard argument for the strategic complementarity of pricing decisions: If a higher competitor price increases the total demand for calls originating in network i , then own price increases are more valuable. There is, however, at least one natural counter-effect: A higher competitor price exacerbates the negative demand effects of an increase in own price, yielding an incentive to reduce own price.

2.4 Do Higher Access Charges Shift Out the Reaction Curves?

The strategic complementarity of pricing decisions in the retail market helps support the argument for collusion among network operators. However, it is

not a *necessary* condition for retail prices to be increasing in access charges. As long as higher access charges shift out reaction curves, both retail prices will go up even if retail prices are strategic substitutes, unless the indirect effects from downward sloping reaction curves are very strong. Conversely, if higher access prices shift reaction curves inward, retail prices are likely to fall. In the following, we show that the latter case may arise in the present setting.

We first suppose that only one firm's access price, a_i , increases. This implies an outward shift of firm i 's reaction curve if

$$\frac{\partial^2 \pi_i}{\partial p_i \partial a_i} = \frac{\partial D_{ji}}{\partial p_i} > 0. \quad (9)$$

That is, if a higher retail price induces more incoming calls, then setting a higher retail price is a reasonable response to a higher access charge. As we argued before, however, this condition may be violated (see (8)).

Next, we ask whether it is natural to expect firm j 's reaction curve to shift outwards when the competitor raises its access price. Such an outward shift occurs if the following condition holds:

$$\frac{\partial^2 \pi_j}{\partial p_j \partial a_i} = -\frac{\partial D_{ji}}{\partial p_j} > 0. \quad (10)$$

(10) requires that the demand for network j 's outgoing calls falls as it raises its retail price. Then, the increasing costs of access to network i make it attractive for network j to curb demand for external calls by increasing its retail price p_j . As argued in before, it is not obvious that $\partial D_{ji}/\partial p_j$ is negative. Summing up, it is not clear that increases in access charges shift out the reaction curves of both firms.

3 Simplifying Assumptions: How Do They Affect the Role of Access Charges?

Our above findings indicate that changes in access charges have subtle effects on retail prices. In particular, they suggest that the collusive role of access charges is not very robust even when retail prices are linear. We now want to

explore to what extent the following two crucial assumptions familiar from the literature affect the role of access charges under network competition (see Vogelsang 2003, p. 846): (i) Full coverage networks, and (ii) balanced calling patterns.

3.1 Full Coverage Networks

In the ALRT framework, the focus is on mature industries where network competition involves competition between two full-coverage networks (see, e.g., Laffont et al. 1998a, 5), and all consumers subscribe to one of the networks. This implies that the total number of subscribers is fixed, i.e.

$$n_i(p_i, p_j) + n_j(p_i, p_j) \equiv n. \quad (11)$$

Therefore, retail prices only affect the networks' market shares

$$\alpha_i(p_i, p_j) \equiv \frac{n_i(p_i, p_j)}{n}, i, j = 1, 2, i \neq j, \quad (12)$$

but not the total number of subscribers (i.e., the “size” of the market).

This simplification tends to support the collusive role of access charges, without eliminating the ambiguities entirely. To see this, note that if (11) holds, we immediately have $\partial n_i / \partial p_i = -\partial n_j / \partial p_i$. We can thus rewrite (3) as

$$\frac{\partial \hat{m}_{ij}}{\partial p_j} = \frac{\partial n_i}{\partial p_j} \left(\frac{\partial m_{ij}}{\partial n_i} - \frac{\partial m_{ij}}{\partial n_j} \right), \quad (13)$$

which is positive by Assumption 1(ii) if and only if the expression in the bracket is positive. One might argue that this condition is likely to be satisfied, since it essentially requires that the number of external calls per subscriber increases more strongly in own network size than it increases in the competitor's network size (the own effect dominates the cross effect).⁹ If this condition is satisfied, we have $\partial \hat{m}_{ij} / \partial p_j > 0$, which reinforces the positive

⁹It should be noted, however, that in this particular case, it is not a foregone conclusion that the own effect dominates the cross effect: The demand for external calls per subscriber should be expected to increase in the number of subscribers to both networks, and without further assumptions on how subscribers choose networks, it is perfectly conceivable that the cross effect dominates.

effect of an increase in network j 's retail price on network i 's total demand, i.e. the full coverage assumption supports the strategic complementarity of retail price decisions.

However, the full coverage assumption does not eliminate the natural counter-effect associated with the negative cross-partial of internal calls. Similar arguments show that the full coverage assumption makes it more likely (but cannot guarantee) that an increase in the access charge shifts out the competitor's reaction curve. Summing up, the full coverage assumption tends to support the collusive role of access charges, but does not guarantee a positive relation between access charges and retail prices.

The ambiguities concerning the collusive role of access charges disappear, however, if we are willing to make a more extreme assumption and fix not only the total number of subscribers, but also the number of subscribers to each network. Making this assumption is equivalent to *ignoring subscription decisions*, which could be justified on the grounds of prohibitive switching costs in a very short-term perspective. In this simpler setting, our earlier concerns about strategic complementarity and the shifting of reaction curves disappear. To see this, consider the strategic complementarity condition (4). The potential counter-effect of the competitor's retail price on external calls, $\partial D_{ij}/\partial p_j$, is zero by assumption: If p_j does not affect n_i and n_j , it cannot affect \hat{m}_{ij} either. Second, all demand functions are now separable in retail prices, as $\partial n_i/\partial p_i = \partial n_i/\partial p_j = 0$ by assumption. Therefore, condition (4) is always satisfied with equality. As to the conditions (9) and (10) assuring that increases in access charges shift out the reaction curves, we have $\partial^2 \pi_i/\partial p_i \partial a_i = \partial D_{ji}/\partial p_i = 0$, since p_i does not affect n_j . Furthermore, by Assumption 1(v), $\partial^2 \pi_j/\partial p_j \partial a_i = -\partial D_{ji}/\partial p_j = -n_j (\partial m_{ji}/\partial p_j) > 0$. Therefore, access charge increases unambiguously shift out the reaction curves of the competitors.

3.2 Full Coverage Networks and Balanced Calling Pattern

Another common simplification in the literature is to require a so-called balanced calling pattern.¹⁰ This means that, at retail prices $p_i = p_j$, inbound and outbound calls are balanced. According to Laffont et al. (1998a, 3), who used the assumption as a “good first approximation” to the possibly complex routing of calls within and across networks, balanced calling patterns also mean that the

“percentage of calls originating on a network and completed on the same network (“on-net calls”) is equal to the fraction of consumers subscribing to the same network.”

We now want to explore how this assumption affects the role of access charges for network competition. We maintain the full coverage assumption from Section 3.1, so that $\alpha_i = n_i(p_i, p_j)/n$.¹¹ Using the notation of Laffont et al. (1998a), our reduced-form demand functions then read

$$D_{ii}(p_i, p_j) = \alpha_i^2(p_i, p_j)q(p_i), \quad (14)$$

$$D_{ij}(p_i, p_j) = \alpha_i(p_i, p_j)(1 - \alpha_i(p_i, p_j))q(p_i), \quad (15)$$

where $q(p_i)$ denotes the call volume per subscriber to network i , with $q'(p_i) < 0$. Note that the call volume per subscriber is a function of p_i alone, whereas in our reduced-form model above, it is a function of both p_i and p_j .¹²

¹⁰Vogelsang (2003, 847) uses the terminology ‘isotropic calling pattern’ instead.

¹¹With the balanced calling pattern assumption, calculations for the reduced-form model become tedious when the total number of subscribers is endogenous.

¹²In a paper closely related to Laffont et al. (1998a), Dessein (2003) combines the assumptions of full coverage and balanced calling patterns with a more flexible demand structure where subscribers may be heterogeneous in the sense that there are light and heavy users initiating call volumes $k_L q(p_i)$ and $k_H q(p_i)$, respectively, with $k_L < k_H$. He finds that in this setting the equilibrium price is still increasing in the access charge (Proposition 1). If, however, the calling pattern is unbalanced, the impact of an increase in the access charge on the equilibrium price may be reversed (Proposition 2). See Section 5 for a discussion of consumer heterogeneity in our reduced-form model.

It is straightforward to show that these assumptions do not resolve the ambiguities outlined above. For instance, consider the strategic complementarity condition (4). Using (14) and (15), we have

$$\frac{\partial D_{ii}}{\partial p_j} = 2\alpha_i \frac{\partial \alpha_i}{\partial p_j} q(p_i) > 0, \quad (16)$$

$$\frac{\partial D_{ij}}{\partial p_j} = \frac{\partial \alpha_i}{\partial p_j} (1 - 2\alpha_i) q(p_i). \quad (17)$$

While (16) is always positive, (17) is positive by Assumption 1(ii) for a small network ($\alpha_i < 1/2$) and negative for a large network ($\alpha_i > 1/2$). That is, from a large network's point of view, the products offered by the different networks are no substitutes. Furthermore, some of the cross-partials of demand may be negative. More specifically, we have

$$\frac{\partial^2 D_{ii}}{\partial p_i \partial p_j} = 2 \frac{\partial \alpha_i}{\partial p_j} \left(\frac{\partial \alpha_i}{\partial p_i} q(p_i) + \alpha_i q'(p_i) \right) < 0, \quad (18)$$

$$\frac{\partial^2 D_{ij}}{\partial p_i \partial p_j} = \frac{\partial \alpha_i}{\partial p_j} (1 - 2\alpha_i) q'(p_i) - 2 \frac{\partial \alpha_i}{\partial p_j} \frac{\partial \alpha_i}{\partial p_i} q(p_i). \quad (19)$$

Condition (18) indicates that $\partial^2 D_{ii} / \partial p_i \partial p_j$ is always negative, whereas the sign of $\partial^2 D_{ij} / \partial p_i \partial p_j$ is ambiguous (see (19)). Thus, the strategic complementarity condition may well be violated.

Furthermore, reaction curves do not generally shift out when access charges increase. To see this, note that

$$\begin{aligned} \frac{\partial^2 \pi_i}{\partial p_i \partial a_i} &= \frac{\partial D_{ji}}{\partial p_i} = \frac{\partial \alpha_i}{\partial p_i} (1 - 2\alpha_i) q(p_j), \\ \frac{\partial^2 \pi_j}{\partial p_j \partial a_i} &= -\frac{\partial D_{ji}}{\partial p_j} = -\frac{\partial \alpha_i}{\partial p_j} (1 - 2\alpha_i) q(p_j) - \alpha_i \alpha_j q'(p_j). \end{aligned}$$

That is, raising the access charge and increasing the retail price is complementary only from a large network's point of view ($\alpha_i > 1/2$). A small network ($\alpha_i < 1/2$), in turn, will not be willing to increase its retail price in response to an increase in its own access charge. To understand this, recall that setting a higher retail price is a reasonable response to a higher access charge if it induces more incoming calls. Under the assumptions of full coverage networks and balanced calling patterns, increasing the retail price will

induce more incoming calls only for a large network, whereas a small network must reduce the retail price to induce more incoming calls.

Interestingly, all of the above ambiguities disappear when networks are symmetric ($\alpha_i = \alpha_j = 1/2$). In this case, all relevant derivatives are either zero or strictly positive, so that the conditions of Proposition 1 are satisfied. In particular, the diverging interests of small and large networks in setting retail prices in response to changes in access charges are perfectly aligned, and increasing access charges (weakly) shifts out reaction curves.

4 Non-linear Retail Tariffs

We now introduce a reduced-form model of two-way network competition with non-linear retail tariffs that incorporates the ALRT framework as a special case.

4.1 Assumptions

Suppose that the networks simultaneously offer two-part retail tariffs of the form

$$T_i(q) = F_i + p_i q,$$

where F_i is a subscriber charge and p_i is the per-unit usage fee. Following Laffont et al. (1998a), we denote the variable gross surplus of a subscriber to network i by $u(m_{ii}, m_{ij})$, and the corresponding variable net surplus by

$$v(p_i) \equiv \max_{m_{ii}, m_{ij}} \{u(m_{ii}, m_{ij}) - p_i(m_{ii} + m_{ij})\}.$$

Accounting for the subscriber charge, the net surplus offered to subscribers of network i is

$$w_i \equiv v(p_i) - F_i.$$

For a fixed retail price p_i , there is a one-to-one correspondence between the subscriber charge F_i and the net surplus w_i , so that we can view the networks as simultaneously choosing p_i and w_i . Also, we confine ourselves to the case

of reciprocal access charges $a_i = a_j \equiv a$. Thus, we write the profit function of firm i as

$$\begin{aligned}\pi_i(w_i, w_j; p_i, p_j) &= (p_i - c)D_{ii}(w_i, w_j; p_i) + (p_i - a - c_1 - c_0)D_{ij}(w_i, w_j; p_i) \\ &\quad + (a - c_0)D_{ji}(w_i, w_j; p_j) + n_i(v(p_i) - w_i) - K_i.\end{aligned}$$

We shall provide a comparative statics result for this reduced form below, but we shall also refer to the following decompositions of the demand functions.

Notation 2 (demand with non-linear tariffs) For $i, j = 1, 2, i \neq j$, we let $n_i(w_i, w_j)$ denote the **number of subscribers** to network i . Further, let $\widehat{m}_{ii}(w_i, w_j; p_i) \equiv m_{ii}(n_i(w_i, w_j), n_j(w_i, w_j), p_i)$ denote the **number of internal calls per subscriber** and $\widehat{m}_{ij}(w_i, w_j; p_i) \equiv m_{ij}(n_i(p_i, p_j), n_j(p_i, p_j), p_i)$ the **number of external calls per subscriber to network i** . Then, the demand functions can be written as

$$\begin{aligned}D_{ii}(w_i, w_j; p_i) &\equiv n_i(w_i, w_j) \cdot \widehat{m}_{ii}(w_i, w_j; p_i), \\ D_{ij}(w_i, w_j; p_i) &\equiv n_i(w_i, w_j) \cdot \widehat{m}_{ij}(w_i, w_j; p_i).\end{aligned}$$

The net surpluses (w_i, w_j) thus both determine the customers' subscription decisions and affect the number of calls per subscriber, whereas the retail prices (p_i, p_j) only affect the number of calls per subscriber. The total effect of a change in the net surplus w_i on the number of internal calls per subscriber, \widehat{m}_{ii} , is given by

$$\frac{\partial \widehat{m}_{ii}}{\partial w_i} = \frac{\partial m_{ii}}{\partial n_i} \frac{\partial n_i}{\partial w_i} + \frac{\partial m_{ii}}{\partial n_j} \frac{\partial n_j}{\partial w_i},$$

and similarly for $\partial \widehat{m}_{ii} / \partial w_j$. The total effect of a change in the competitor's net surplus w_j on the number of external calls is

$$\frac{\partial \widehat{m}_{ij}}{\partial w_j} = \frac{\partial m_{ij}}{\partial n_i} \frac{\partial n_i}{\partial w_j} + \frac{\partial m_{ij}}{\partial n_j} \frac{\partial n_j}{\partial w_j},$$

and similarly for $\partial \widehat{m}_{ij} / \partial w_i$. We adapt Assumptions 1 and 2 from above in the following way:

Assumption 1' (demand properties) *The components of demand satisfy the following properties:*

(i) n_i, m_{ii} and m_{ij} are differentiable functions.

(ii) $\partial n_i / \partial w_i > 0$; $\partial n_i / \partial w_j < 0$.

(iii) $\partial m_{ii} / \partial n_i > 0$; $\partial m_{ii} / \partial n_j < 0$.

(iv) $\partial m_{ii} / \partial p_i < 0$.

(v) $\partial m_{ij} / \partial p_i < 0$.

Assumption 2' (separability) *The demand components are separable in retail prices and net surpluses, i.e.*

$$\begin{aligned} \frac{\partial^2 n_i}{\partial w_i \partial w_j} = 0, \quad \frac{\partial^2 \hat{m}_{ii}}{\partial w_i \partial w_j} = 0, \quad \text{and} \quad \frac{\partial^2 \hat{m}_{ij}}{\partial w_i \partial w_j} = 0; \\ \frac{\partial^2 \hat{m}_{ii}}{\partial p_i \partial w_i} = 0, \quad \frac{\partial^2 \hat{m}_{ij}}{\partial p_i \partial w_i} = 0. \end{aligned}$$

4.2 Comparative Statics

We now discuss how changes in access charges affect subscriber charges and usage fees. To some extent the intuition will parallel the case of linear pricing. However, there is added complexity from the interaction of usage fees p_i and subscriber charges F_i (or equivalently, net surpluses w_i). The following three arguments are key for the notion that both usage fees and net surpluses should be increasing in access charges.

- (i) Setting a higher access charge a increases the marginal benefits from an increase in the usage fee p_i .
- (ii) Other things being equal, charging a higher usage fee p_i increases the marginal profitability from setting a higher net surplus w_i (by lowering the subscriber charge F_i). Intuitively, a network charging a high usage fee benefits more from a larger customer base which it obtains thanks to a low subscriber charge.
- (iii) The different players' decision variables, which are now two-dimensional (usage fee and net surplus), are strategic complements. Thus, a firm's optimal response to an increase of the usage fee and an increase of

the net surplus of the competitor involves increasing its own usage fee and increasing its own net surplus (i.e., reducing its own subscription charge).

Using these arguments, the following response to an access charge increase appears plausible. First, by (i), the direct effect of a higher access charge is to increase usage fees. Second, by (ii), if firms increase their usage fees, they should reduce subscriber charges. Third, by (iii), these adjustments of both firms to higher access charges reinforce each other.

The intuition is slightly incomplete, however, as one must also take the direct effect of higher access charges on subscription charges into account. Unfortunately, neither the standard monopoly non-linear pricing problem, nor the linear access pricing model of Section 2 offers guidance for the sign of this effect. Next, we therefore state a comparative statics result that contains a suitable condition on this direct effect as well as formalizations of (i)–(iii) above, and then discuss the plausibility of these conditions.

Proposition 2 (two-part tariffs) *For the reduced-form model with two-part retail tariffs, suppose the following conditions hold for $i, j = 1, 2; i \neq j$:*

- (i) $\frac{\partial^2 \pi_i}{\partial a \partial p_i} \geq 0; \frac{\partial^2 \pi_i}{\partial a \partial w_i} \geq 0;$
- (ii) $\frac{\partial^2 \pi_i}{\partial p_i \partial w_i} \geq 0;$
- (iii) $\frac{\partial^2 \pi_i}{\partial p_i \partial p_j} \geq 0; \frac{\partial^2 \pi_i}{\partial p_i \partial w_j} \geq 0; \frac{\partial^2 \pi_i}{\partial w_i \partial p_j} \geq 0; \frac{\partial^2 \pi_i}{\partial w_i \partial w_j} \geq 0.$

Then, an increase in the access charge a leads to an increase in the equilibrium values of (p_1, p_2) and (w_1, w_2) .

Proof. By (i), each objective function $\pi_i(p_i, p_j, w_i, w_j; a)$ has increasing differences in $(p_i, w_i; a)$. By condition (ii), the objective functions are supermodular in (p_i, w_i) . By condition (iii), they also satisfy increasing differences in $(p_i, p_j; w_i, w_j)$. Taking (ii) and (iii) together, the game is supermodular. Thus, applying Milgrom and Roberts (1990, Th. 5) yields the result. ■

We now clarify to what extent the conditions of Proposition 2 are likely to hold.

First, consider the direct effects in (i) given by

$$\frac{\partial^2 \pi_i}{\partial a \partial p_i} = -\frac{\partial D_{ij}}{\partial p_i} > 0 \quad \text{and} \quad \frac{\partial^2 \pi_i}{\partial a \partial w_i} = \frac{\partial D_{ji}}{\partial w_i} - \frac{\partial D_{ij}}{\partial w_i}.$$

The direct effect of access charges on usage fees is always positive as higher usage fees lead to less outgoing calls by Assumption 1'(v).¹³ The direct effect of access charges on net surpluses is less obvious. In the model proposed by Laffont et al. (1998a), this effect turns out to be zero, as demand functions are given by

$$\begin{aligned} D_{ji} &= \alpha_i(w_i, w_j)(1 - \alpha_i(w_i, w_j))q(p_j), \\ D_{ij} &= \alpha_i(w_i, w_j)(1 - \alpha_i(w_i, w_j))q(p_i), \end{aligned}$$

so that $\partial D_{ji}/\partial w_i = \partial D_{ij}/\partial w_i$ for $p_i = p_j$.

Second, consider the within-player effects (ii). Even without using the demand decomposition, we obtain a somewhat lengthy expression for the relevant cross-partial:

$$\begin{aligned} \frac{\partial^2 \pi_i}{\partial p_i \partial w_i} &= \frac{\partial D_{ii}}{\partial w_i} + (p_i - c) \frac{\partial^2 D_{ii}}{\partial p_i \partial w_i} + \frac{\partial D_{ij}}{\partial w_i} \\ &+ (p_i - a_j - c_1 - c_0) \frac{\partial^2 D_{ij}}{\partial p_i \partial w_i} + \frac{\partial n_i}{\partial w_i} v'(p_i). \end{aligned} \quad (20)$$

Rather than considering each term in (20), we highlight some major effects. There are clear forces supporting the idea of complementarity between high usage fees and high net surpluses. For instance, we unambiguously have

$$\frac{\partial D_{ii}}{\partial w_i} = \frac{\partial n_i}{\partial w_i} \hat{m}_{ii} + n_i \frac{\partial \hat{m}_{ii}}{\partial w_i} > 0.$$

Intuitively, this reflects the idea that with a high net surplus, the total number of subscribers and thus the volume of internal calls will be high, so that the per-unit profits resulting from a higher usage fee apply to a greater customer base. However, there are also counter-effects. For instance, arguments

¹³The indirect effects from the linear pricing model are no longer present, because subscriptions only depend on prices via net surpluses.

as in Section 2 show that

$$\frac{\partial^2 D_{ii}}{\partial p_i \partial w_i} = \frac{\partial n_i}{\partial w_i} \frac{\partial \widehat{m}_{ii}}{\partial p_i} + n_i \frac{\partial \widehat{m}_{ii}}{\partial w_i}$$

is likely to be negative: A higher net surplus leads to more subscriptions. Thus, the reduction in internal calls resulting from a higher usage fee has a particularly strong negative demand effect, as it applies to a greater number of subscribers. More interestingly, there is a negative subscription charge effect that is specific to the non-linear case ($(\partial n_i / \partial w_i) v'(p_i) < 0$): When w_i is high, firm i has a large number of subscribers. Increasing the usage charge means that the firm will be able to extract a smaller subscription charge from each customer. This effect is particularly pronounced when the number of subscribers is large.

Finally, consider strategic interactions. First note that $\partial^2 \pi_i / \partial p_i \partial p_j = 0$, which is in line with condition (iii). The remaining cross-partials, however, are typically ambiguous. For instance,

$$\begin{aligned} \frac{\partial^2 \pi_i}{\partial p_i \partial w_j} &= \frac{\partial D_{ii}}{\partial w_j} + (p_i - c) \frac{\partial^2 D_{ii}}{\partial p_i \partial w_j} + \frac{\partial D_{ij}}{\partial w_j} \\ &+ (p - a_j - c_1 - c_0) \frac{\partial^2 D_{ij}}{\partial p_i \partial w_j} + \frac{\partial n_i}{\partial w_j} v'(p_i), \end{aligned} \quad (21)$$

is very similar to (20), except that the derivatives are taken with respect to w_j rather than w_i . Typically, however, derivatives with respect to w_i and w_j have different signs, which makes it unlikely that $\partial^2 \pi_i / \partial p_i \partial w_j$ and $\partial^2 \pi_i / \partial p_i \partial w_i$ have the same sign.

Summing up, there is some support for the intuitive notion that higher access charges tend to both increase usage fees and decrease subscriber charges. However, higher access charges may have positive direct effects on fixed fees ($\partial^2 \pi_i / \partial a \partial w_i \leq 0$), even though this is not the case in the model proposed Laffont et al. (1998a). Further, the strategic complementarity of the players' two-dimensional decision vectors is not obvious. While this does not itself imply that the conclusions of Proposition 2 do not hold—after all, these conditions are merely sufficient rather than necessary—it does at least warn us that straightforward intuitive reasoning may not apply under two-sided network competition.

5 Extensions and Conclusions

We finally discuss two important extensions of the ALRT framework that have been studied in the literature: (i) customer heterogeneity (Dessein 2003), and (ii) price discrimination based on call termination (Laffont et al. 1998b).

First, note that the extension to heterogeneous customers is straightforward, as our reduced-form demand functions D_{ii} and $D_{ij}, i, j = 1, 2, i \neq j$, are perfectly consistent with customer heterogeneity: Suppose that there are t types of customers indexed by $k = 1, \dots, t$. Let n_i^k denote the number of type k customers subscribing to network i . Similarly, let \hat{m}_{ii}^k and \hat{m}_{ij}^k denote the number of internal and external calls, respectively, per subscriber of type k . Then, the demand for internal and external calls is given by $D_{ii} \equiv \sum_k n_i^k \hat{m}_{ii}^k$ and $D_{ij} \equiv \sum_k n_i^k \hat{m}_{ij}^k$, respectively. Since Propositions 1 and 2 are formulated in terms of reduced-form demand functions, they also apply when customers are heterogenous. Therefore, the ambiguities with respect to possible collusion over inflated access charges still emerge in this more general case, even after extending our assumptions on the demand components to all t types of customers.

Second, consider the case where networks charge different retail prices for internal and external calls. Following Laffont et al. (1998b), we denote the retail price of network i for internal calls by p_i and the price for external calls by \hat{p}_i .¹⁴ Clearly, we cannot simply reinterpret Propositions 1 and 2 to understand the sufficient conditions for retail prices to be increasing in access charges in such a setting. Our above analysis suggests, though, that collusion over inflated access charges is unlikely to be a robust phenomenon in this more general setting, as it is inherently non-robust even in the special case where $p_i \equiv \hat{p}_i$.¹⁵

Summing up, this paper provides a reduced-form analysis of the role of access charges under two-way network competition with linear and non-linear retail prices. Retaining the key features of network competition models but

¹⁴In the case of non-linear retail tariffs, network i also sets a subscriber charge F_i (as in Section 4).

¹⁵Laffont et al. (1998b, 40), for instance, find that “raising each other’s cost does not promote collusion” in their model with price discrimination.

imposing less structure, we derive sufficient conditions for usage fees to be increasing (and subscriber charges to be decreasing) in access charges. We show that these conditions are difficult to satisfy without making rather strong assumptions on the demand for calls within and across networks, suggesting that implementing collusion by inflating access charges is likely to be non-feasible. Our results extend Dessein's (2003) earlier finding that making the analytical framework more general does not restore the collusive effect of a high access charge.

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