Mobile Access Charges and Collusion under Asymmetry

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Abstract

This paper considers collusion between asymmetric networks in the telecommunications industry. Its primary purpose is to fill the gap between the literature on collusion between asymmetric firms and the literature on collusion in the telecommunications industry. Employing the standard Hotelling framework of horizontal product differentiation with non-linear tariffs and network based price discrimination we allow for differentiation in a second dimension. Modulo locations, the subscribers to each network operator face an asymmetry parameter that directly impacts their demands and can capture asymmetries in demand elasticities, in demand size, or even both. The implications of these asymmetries for the possibility of sustaining collusion are investigated under alternative access pricing regimes.

Résumé

Cet article analyse la concurrence dans le secteur des télécommunications dans le cadre de réseaux asymétriques. A partir du modèle standard de différenciation horizontale sur les produits avec tarifs non linéaires et discrimination du prix des appels, nous envisageons une différenciation dans une deuxième dimension. Selon leur localisation, les consommateurs de chaque opérateur de réseau font face à un paramètre d'asymétrie qui influe directement sur leurs demandes et peuvent capturer des différences d'élasticités ou de taille. Les implications de ces asymétries quant à la possibilité de maintenir la collusion sont étudiées sous des régimes alternatifs de tarification d'accès aux réseaux.

JEL Codes: D43,L11, L13

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1 Introduction

Network interconnection is undoubtedly one of the main issues in the development of competitive marketplaces for wireless services. Since the introduction of competition in the European mobile market, National Regulatory Authorities (NRAs) have always been very concerned about call termination. Call termination is a wholesale service provided by network operators that allows to terminate a call made by callers to subscribers of a competing network. As each mobile operator has a monopoly over the termination of calls on its network, regulatory policy has been particularly attentive to the termination rates charged by mobile operators. In European countries, regulation has been implemented through a *glide path* that prescribes a reduction of Mobile Termination Rates (MTRs) over years.

Furthermore, mobile operators often have highly asymmetric networks (e.g. incumbents/entrants) and regulation has set asymmetric MTRs in order to compensate for this. For example initially smaller networks of entrants or networks with costs or technology disadvantages have benefited from higher regulated termination charges.[1] The glide path implemented by European regulators implied a gradual decrease in asymmetric regulation as new entrants in the mobile market got more significant market shares. Baranes and Vuong (2012a) present more details about the policy implications of asymmetric termination rates and the European glide path regulation. The following Figure 1, shows that average MTRs are decreasing over the years in the European countries, while Table 1 illustrates the asymmetric glide paths of MTRs using French data.

INSERT FIGURE 1 here

INSERT TABLE 1 here

In Europe where most countries have adopted the calling-party-pays model, national NRAs have initiated numerous investigations into mobile markets. Often these investigations were motivated by the suspicion that mobile operators were able to employ termination rates anticompetitively. French authority found the three national mobile operators guilty of collusion and imposed a fine of Euro 534 million, equivalent to about 3.5% of annual revenue of the companies involved. In the present case, the French competition authority found the three operators had shared strategic information on subscribers and entered into an agreement to stabilize their market shares (see Autorité de la Concurrence, 2005). It is usually hard

[1] Gruber (2005, p.163ff and p.181ff) presents empirical studies that find significant switching costs and hence demand side asymmetries for the mobile market.

for the authorities to find explicit evidence of price collusion with this case being no exception. However one can safely argue that termination rates played a major role in implementing collusion between these mobile companies.

The literature on network interconnection and pricing strategies in the telecommunications industry[2] originating in the work of Armstrong (1998) and Laffont *et al.* (1998ab) has generically assumed that competition takes place between symmetric networks. This assumption of symmetry is a most welcome simplifying device to keep the analysis of the pricing vectors that form the Nash equilibrium of the game tractable. However, in most cases of regulatory concern it is a later entrant that competes against an incumbent with an established market share and possibly also against substantial switching costs. Thus the symmetry assumption of previous models, being the source of various 'profit neutrality results', see Laffont *et al.,* (1998a) and Dessein (2003), seems to be unfortunate.

Previous research in asymmetric telecommunication environments is still quite scarce. Carter and Wright (2003) show that, given that access charges have to be chosen reciprocally (i.e. symmetrically), firms may prefer them to be set at cost if size differences are pronounced. Peitz (2005) investigates the issue of asymmetric regulation but focuses on entry and consumer surplus. Hoernig (2007) finds evidence that larger firms will tend to have a larger price differential between its on- and off-net prices, but does not explicitly model access charges. Stühmeier (2012) extend the analysis to asymmetric termination costs. Hoernig (2014) allows for asymmetric market shares with more than two firms and also looks at mobile-to-mobile call termination, however only in a symmetric setting.

As shown in Behringer (2012), one can find non-reciprocal equilibrium access charges with a positive markup on termination cost as observed in regulatory practice, but not in the earlier models under price discrimination, by assuming that such charges are chosen non-cooperatively (as in Behringer (2009)), and that networks are potentially asymmetric. This gap in the literature has been noted as early as in Armstrong (2002: 373) and Geoffron and Wang (2008) employ the same modelling of asymmetry to investigate the effects of calling clubs. The urgency for theoretical models to accommodate these practical concerns is emphasised in Hurkens and López (2014), who modify the consumer expectations used in Laffont *et al.* model.[3] A collective early volume dedicated to the issue of asymmetries in mobile markets intended to increase realism of previous modelling, as demanded in a study for the European Commission (see Tera, 2009, p.133) is Benzoni and Geof-

[2]Early works on the industrial organization of telecommunications can be found in Picard (1988) and Laffont and Tirole (1995).

[3] Other explanations for positive markups are provided in Armstrong and Wright (2009), Jullien *et al.* (2013), and Hoernig *et al.* (2014).

fron (2007). Baranes and Vuong (2012b) analyse competition between asymmetric mobile network operators and examine how asymmetric regulation can impact on the incentives of the entrants to upgrade their technologies. Recently, López and Rey (2015) also look at asymmetric duopoly (due to switching costs) with a focus on market foreclosure.

From the very beginning the issue of collusion has been present in the analysis of the telecommunication industry. For an introductory overview see Peitz et al. (2004). However, almost all theoretical investigations focus on the effect of access charges on the retail price components. An exception is the work of Höffler (2009), who looks at collusion in the classical way in an infinitely repeated Bertrand competition setting with heterogeneous consumers. Again, however, the firms are assumed to be symmetric.

The influence of asymmetry on collusion had been analyzed in a more general framework by Vasconcelos (2005). This contribution finds that, if the asymmetry is on the supply (cost) side of a Cournot setting, the sustainability of collusion will depend on the most extreme firms only. Similarly in a differentiated Bertrand setting under asymmetric capacity constraints, Comte et. al. (2002) find that the firm with the largest capacity will benefit most from deviation and a small firm is less able to inflict punishments. Thus it is the largest firm that is most critical for the sustainability of collusion. Consistently with the consensus, both papers share the prediction that more symmetric firms (in costs and capacities) will make collusion easier to sustain.[4] One of the few recent papers that have joined the issues of asymmetric firms with the incentives to collude is Baranes and Poudou (2009). Their model allows for differing price sensitivities of consumer demands (e.g. resulting from switching costs) and for access charges. Using a model that employs a differentiated duopoly framework, they find that symmetry in access regulation may actually inhibit collusion.

Our paper considers collusion between asymmetric networks in the telecommunications industry. Its primary purpose is to fill the gap between the literature on collusion between asymmetric firms and the literature on collusion in the telecommunications industry. The paper extends the concern with direct collusion to the telecommunications industry, employing a standard horizontal differentiation Hotelling setup with two-part tariffs and network based price discrimination. It allows for a general demand form that encompasses various possible origins of asymmetries. The implications of asymmetries for the possibility of sustaining collusion collusion are then investigated under alternative access pricing regimes.

[4]This observation also is the founding block for the paper of Boone (2004).

Section 2 presents the model in which the competitive, the collusive, and the deviation outcome are laid out and Section 3 the respective equilibria. Section 4 and 5 investigate how the critical discount factors are affected by potential asymmetries of the networks in demand, in costs and/or in access pricing regimes. Section 6 concludes. The proofs are relegated to the Appendix.

2 Model setup

The following model uses the setting of the network competition models of Laffont *et al.* (1998a,b) with duopolistic competition in two-part tariffs, on-net and off-net price discrimination, and balanced calling patterns. In order to clarify the presentation of the model we recall that the setup used in Laffont *et al.* (1998a,b) is as follows: In a first step an arbitrary access charge[5] is determined by a regulator or an arbitrator. Then firms compete in prices where price discrimination between on-net and off-net calls is allowed as obseved in practice. In the following we do not address the question of optimal access charges for the firms or from the point of view of static social welfare which is investigated in Behringer (2009, 2012). Instead we consider the question of collusion sustainability (and hence dynamic welfare) in the telecommunications industry allowing for general demand asymmetries. As in Carter and Wright (1999, 2003) we allow explicitly for an exogenous asymmetry between networks. In contrast, we assume that the asymmetry is directly related to the demand for calls. This implies that the asymmetry does not simply impact the fixed utility, but affects the volume of calls. We then consider the question of collusion sustainability in the telecommunications industry by focusing on the role of this demand asymmetry.

Demand asymmetry. To model the demand asymmetry between networks, we assume the consumer demand for calls to be given by $q(p, \eta)$ where p is the unit price and η indicates the asymmetry. This parameter can represent the elasticity of demand or measure the size of the demand (or network), or can be generalized to any other type of heterogeneity with relative importance for each network. In our duopoly setting, we write η_i for the parameter describing network i, with $i = 1, 2$. Considering network i, we assume that the asymmetry parameter exceeds a given level $\eta_i \geq \eta_0$. Networks are symmetric if $\eta_i = \eta_0$ ($\forall i = 1, 2$) and asymmetric otherwise, where η_0 is the symmetric benchmark which we normalize to zero without

[5]The term "access charge" as used in the present paper is often referred to as "termination rate" or "termination fee" in regulatory practice. We prefer to use the term "access charge" as a reference to the traditional more general literature initiated by Laffont and Tirole (1995) and Laffont *et al.* (1998a,b).

loss of generality. The net surplus $v(p,\eta)$ a consumer gets from consuming q unit of calls is given by

$$v(p,\eta) \equiv \int_p^{\infty} q(\zeta,\eta)d\zeta = u(q(p,\eta),\eta) - pq(p,\eta)$$

where $u(q,\eta)$ represents the gross utility from making q calls.

We make the following standard assumptions both on demand and indirect utility[6]: $q_1(p,\eta) < 0$ and $v_1(p,\eta) = -q(p,\eta) < 0$, $\forall\ (p,\eta)$. This implies that both quantity and indirect utility are decreasing functions of unit price. Moreover we maintain the following:

Assumption. *For all* (p,η), *the demand and indirect utility functions either satisfy A.1:* $\operatorname{sgn}(q_2(p,\eta)) = \operatorname{sgn}(v_2(p,\eta)) < 0$ *or, A.2:* $\operatorname{sgn}(q_2(p,\eta)) = \operatorname{sgn}(v_2(p,\eta)) \geq 0$.

Assumptions *A.1* and *A.2* deserve more comment. For a given price, the effects of asymmetries on demand and indirect utility coincide. This implies that if the asymmetry has a decreasing impact on demand it will also decrease the consumer indirect utility and vice versa. Assume $\eta_1 \geq \eta_2$, then Assumption *A.1* implies that both demand and indirect utility derived from network 1 are always lower than those derived from network 2. The reverse holds for Assumption *A.2*.

To illustrate Assumptions *A.1* and *A.2*, we consider the following examples:

Example 1 (isoelastic demand): The isoelastic demand function is given by $q(p,\eta) = A(\eta)\,p^{-\epsilon(\eta)}$, where $A(\eta) > 0$ reflects the size of the demand (or network) and $\epsilon(\eta) > 1$ is the elasticity of demand. The indirect utility is then $v(p,\eta) = \frac{A(\eta)p^{1-\epsilon(\eta)}}{\epsilon(\eta)-1}$. First assume that the asymmetry weighs fully on the demand size, i.e. $A(\eta) = \eta$ and $\epsilon(\eta) = \epsilon$. Then one can see that $q_2(p,\eta) = p^{-\epsilon} > 0$ and $v_2(p,\eta) = \frac{p^{1-\epsilon}}{\epsilon-1} > 0$, so Assumption *A.2* holds. Now consider that the asymmetry weighs fully on the demand elasticity, i.e. $A(\eta) = A$ and $\epsilon(\eta) = \eta$. Then $q_2(p,\eta) = -\ln(p)q(p,\eta) < 0$ and $v_2(p,\eta) = -\frac{(1+(\eta-1)\ln(p))v(p,\eta)}{(\eta-1)} < 0$, for a given price $p > 1$, then the Assumption *A.1* holds.

Example 2 (linear demand): Consider the linear demand function given by $q(p,\eta) = A(\eta) - B(\eta)\,p$, where $A(\eta) > 0$ is the size of the demand (or network) and $B(\eta) > 0$ corresponds to a slope parameter that increases[7] the elasticity of demand for a given price. The indirect utility function is then $v(p,\eta) = \frac{1}{2B(\eta)}q(p,\eta)^2$. Hence, if we assume that the asymmetry weighs fully on the demand size, i.e. $A(\eta) = \eta$

[6]Hereafter lower indices denote the position of the argument of the function for which the partial derivative is taken.

[7]Clearly $B(\eta)$ is not the elasticity here, it writes $\epsilon = B(\eta)\,p/q(p,\eta)$. However, increasing $B(\eta)$ increases the demand elasticity since $d\epsilon/dB(\eta) = A(\eta)\,p/q(p,\eta)^2 > 0$.

and $B(\eta) = B$, then one can see that $q_2(p,\eta) = 1 > 0$ and $v_2(p,\eta) = q(p,\eta)/B > 0$, and Assumption *A.2* holds. Assumption *A.1* holds if the asymmetry weighs fully on the elasticity proxy parameter B, i.e. $A(\eta) = A$ and $B(\eta) = \eta$. In this case, both demand and indirect utility are decreasing functions of η, i.e. $q_2(p,\eta) = -p < 0$ and $v_2(p,\eta) = -\frac{1}{2\eta^2} q(p,\eta)(A + \eta p) < 0$.

Network market shares and profits. We now consider competition between two networks, $i = 1, 2$ located at the opposite ends of a Hotelling unit line, where network 1 is located at $x = 0$ and network 2 is located at $x = 1$. Consumers are assumed to be uniformly distributed on that unit line and the transportation cost is denoted by $\theta > 0$ per unit. Both networks offer a two-part tariff to consumers including the fixed fee f_i, the on-net unit price p_i, and the off-net unit price $\hat{p}_i$. Given a balanced calling pattern a consumer joining network i obtains a net total surplus given by

$$w_i = \alpha_i v(p_i, \eta_i) + (1 - \alpha_i) v(\hat{p}_i, \eta_i) - f_i \tag{1}$$

where α_i denotes the market share of network i.

Given the unit transportation cost θ a consumer who is located at $x \in [0, 1]$ gets an overall utility $U_1(x) = w_1 - \theta x$ when joining network 1, and $U_2(x) = w_2 - \theta(1 - x)$ when joining network 2. The marginal consumer between network 1 and 2 is defined by $\hat{x} \equiv (\theta + w_1 - w_2)/2\theta$ and its overall utility level is $\hat{U} = U_1(\hat{x})$. We restrict attention to market conditions for which the market is fully covered by the networks.[8] This will be the case in particular when the networks are very similar (η_1 close to η_2) and the access charges are cost-based (a_1 and a_2 close to c_0). To ensure this formally, we assume that the networks are moderately differentiated so that,

$$\frac{2}{3} v(2c_0, 0) \geq \theta \geq \frac{2}{7} v(2c_0, 0) \tag{2}$$

at $\eta_0 = 0$, the symmetric benchmark level. The market shares of the two networks are given by $\alpha_1 = \hat{x}$ and $\alpha_2 = 1 - \hat{x}$.

Each network bears a fixed cost normalised to 0 and a common marginal costs c_0 at the originating and the terminating end of each call. Network i pays an access price a_i for each off-net call from network j that terminates in its network. Thus, the per unit cost of an off-net call is $c_0 + a_i$ and the per unit cost of an on-net call is $2c_0$.

[8] Full market coverage is a common and simplifying assumption used in most models. Exceptions are Schiff (2002) and Baake and Mitusch (2009).

Setting the two-part tariff $(f_i, p_i, \hat{p}_i)$, the profit function for network i is

$$\begin{aligned}\pi_i\left(p_i, \hat{p}_i; p_{-i}, \hat{p}_j\right) &= \alpha_i \left\{\alpha_i q(p_i, \eta_i)(p_i - 2c_0) + (1-\alpha_i) q(\hat{p}_i, \eta_i)(\hat{p}_i - c_0 - a_j)\right. \\ &\quad \left. + (1-\alpha_i) q(\hat{p}_j, \eta_j)(a_i - c_0) + f_i\right\}\end{aligned}$$

where $q(p_i, \eta_i)$ and $q(\hat{p}_i, \eta_i)$ are the number of on-net and off-net calls of network i respectively.

From (1) we have $f_i = \alpha_i v(p_i, \eta_i) + (1-\alpha_i) v(\hat{p}_i, \eta_i) - w_i$ and we can rewrite the profit of network i as

$$\begin{aligned}\pi_i\left(\mathbf{p}, \mathbf{w}\right) &= \alpha_i \{\hat{x} q(p_i, \eta_i)(p_i - 2c_0) + (1-\alpha_i) q(\hat{p}_i, \eta_i)(\hat{p}_i - c_0 - a_j) + \\ &\quad + (1-\alpha_i) q(\hat{p}_j, \eta_j)(a_i - c_0) + \alpha_i v(p_i, \eta_i) + (1-\alpha_i) v(\hat{p}_i, \eta_i) - w_i\}\end{aligned} \tag{3}$$

We next define two shorthand notations for the indirect utility difference functions $V_{ij}\left(y, z\right) \equiv v(y, \eta_i) - v(z, \eta_j)$ and revenues $R_i\left(y, z, t\right) \equiv (y - z) q(t, \eta_i)$.

Collusion. As is standard in the classical analysis of tacit collusion (Friedman 1971), we consider an infinitely repeated tariff competition game. The punishment strategy for a given operator corresponds to a trigger strategy with reversion to the static competitive equilibrium. We denote the individual profit gained from a punishment strategy (Nash reversion to competition) as π_i^* and the individual collusion profit as π_i^C. Finally the individual profit gained from deviating from the collusive agreement is π_i^D. As is well known, the fully collusive outcome can be sustained as a subgame-perfect equilibrium of the infinitely repeated game if the intertemporal discount factor δ is sufficiently large, i.e.

$$\delta_i \geq \hat{\delta} = \max\{\hat{\delta}_1, \hat{\delta}_2\} \tag{4}$$

where $\hat{\delta}$ denotes the critical discount factor and $\hat{\delta}_i = (\pi_i^D - \pi_i^C)/(\pi_i^D - \pi_i^*)$ represents the critical discount factor for network i.

We next investigate the levels and variations of the critical discount factor $\hat{\delta}$ with respect to both the reciprocal access charge regulation and the potential asymmetry of the networks. This will help us to asses how incentives to collude are driven by these two features in this industry. Note that, if the critical discount factor decreases, firms are able to collude for a larger range of individual discount factors and conversely. As a result any factor that pushes down the critical discount factor should be considered as a factor that *facilitates collusion* in the industry. If the critical discount factor is pushed up, the factor *inhibits collusion.* Our aim is to identify how asymmetric access charge regulation is such a facilitating or inhibiting factor when networks become more asymmetric. To perform this analysis we will look at the equilibrium outcomes for each operator corresponding to the three different market configurations.

3 Equilibrium outcomes

In this section we determine the equilibrium outcomes for each market configuration (competition, collusion, and deviation). Let us start with the competitive outcomes.

The competitive outcomes. This situation is the one studied by Laffont *et al.* (1998b). The equilibrium fixed fee and the price vector components of network i satisfy $(p_i^*, \hat{p}_i^*, f_i) = \arg\max_{p_i,\hat{p}_i,f_i} \pi_i (p_i, \hat{p}_i; p_j, \hat{p}_j)$. The result of the maximization is stated in the following Lemma.

Lemma 1 (Laffont *et al.*, 1998b). *The equilibrium unit prices and the fixed fee of network i in the competitive setting are:*

(i) $p_i^* = 2c_0$ *and* $\hat{p}_i^* = c_0 + a_j$

(ii) $f_i^* = \dfrac{\pi_i^*}{\alpha_i^*} - (1-\alpha_i^*)R\left(a_i, c_0, \hat{p}_j^*, -i\right)$.

Lemma 1 states the standard results for competitive equilibrium prices. Equilibrium unit prices are equal to their respective marginal costs. Hence, on-net prices are set at the total marginal cost of an on-net call ($2c_0$) and off-net prices are set to their marginal cost including the unit access charge of the competing network ($c_0 + a_j$), i.e. the total 'perceived marginal cost'. Equilibrium fixed fees are then used by networks to extract surplus from consumers.

It follows that equilibrium market shares as determined by the marginal consumer are

$$\alpha_1^* = \frac{\theta + V_{1,2}\left(\hat{p}_1^*, p^*\right) - f_1^* + f_2^*}{2\theta + V_{1,1}\left(\hat{p}_1^*, p^*\right) + V_{2,2}\left(\hat{p}_2^*, p^*\right)} \quad \text{and } \alpha_2^* = 1 - \alpha_1^*$$

Using (3), we obtain the competitive equilibrium profit of network i, denoted by $\pi_i^*\left(a_i, a_j, \eta_i, \eta_j\right)$ as given in the Appendix. We highlight the fact that these equilibrium profits are functions of the access charges (a_1, a_2) and the elasticity parameters (η_1, η_2). Note that when access charges are cost-based and symmetry holds, the profit of network i is simply equal to $\pi_i^*\left(c_0, c_0, 0, 0\right) = \theta/2$.

The collusive outcomes. In order to determine the fully collusive outcome we assume that the price vector maximizes the joint profit subject to the participation constraint for all consumers. Then collusive unit prices and the fixed fee result from the constrained maximization problem $\max_{\mathbf{p},\mathbf{f}} \pi_1\left(\mathbf{p}, \mathbf{w}\right) + \pi_2\left(\mathbf{p}, \mathbf{w}\right)$ s.t. $\hat{U} \geq 0$. The solution is as follows.

Lemma 2. *The equilibrium unit prices and the fixed fee of network i in the collusive setting are* *(i)* $p_i^C = \hat{p}_i^C = 2c_0$*, for* $i = 1, 2$*,*

(ii) $f_i^C = \frac{1}{4}\left(3v(2c_0, \eta_i) + v(2c_0, \eta_j)\right) - \frac{1}{2}\theta$*.*

Note that this collusive equilibrium corresponds to the multiproduct monopolistic outcome when a two-part tariff is charged. All collusive marginal prices are set to the marginal cost in order to enhance the network's productive efficiency and the fixed fees are used to capture almost the entire consumer's surplus (and the entire surplus of the indifferent consumer).

Using (3) and substituting into the equilibrium collusive prices, we obtain the equilibrium profit of network i for the collusive setting that we denote $\pi_i^C\left(a_i, a_{-i}, \eta_i, \eta_{-i}\right)$. When the access charges are cost-based and symmetry holds, the profits are simply $\pi_i^C\left(c_0, c_0, 0, 0\right) = \left(2v\left(2c_0, 0\right) - \theta\right)/4$, which is positive under (2).

The deviation outcomes. We assume without loss of generality that it is network i that deviates from the collusive outcome. The deviation unit prices and the fixed fee are then derived from the constrained maximization problem $\max_{p_i, \hat{p}_i, f_i} \pi_i\left(p_i, \hat{p}_i, p_{-i}^C, \hat{p}_{-i}^C, f_i, f_{-i}^C\right)$ s.t. $\hat{U} \geq 0$. Therefore the solution is as follows:

Lemma 3. *The equilibrium unit prices and the fixed fee in the deviation setting are:*

(i) $p_i^D = p_i^*$ *and* $\hat{p}_i^D = \hat{p}_i^*$

(ii) $f_i^D = \dfrac{\pi_i^D}{\alpha_i^D} - (1 - \alpha_i^D) R\left(a_i, c_0, p^*, -i\right).$

Note that network i deviates from the collusive equilibrium using its fixed fee while leaving unit on-net and off-net prices unchanged. In doing so, network i can attract more consumers and increase its overall profit. The corresponding equilibrium deviation profit of network i is denoted $\pi_i^D\left(a_i, a_{-i}, \eta_i, \eta_{-i}\right)$ and details are given in the Appendix.

Again with reciprocal access charges, deviation profits are equal for the two operators. For both of them, cost-based access charges and symmetry imply profits of $\pi_i^D\left(c_0, c_0, 0, 0\right) = \left(2v\left(2c_0, 0\right) + \theta\right)^2/32\theta$.

A thorny issue when looking at deviation outcomes is that monopolization can occur ex-post, with the deviating firm remaining the only firm in the market. To avoid this, we restrict our model to market conditions that preserve a duopolistic structure when firms deviate. With condition (2), network i's market share α_i^D always belongs to the interval $[0, 1]$ when $(a_i, a_{-i}, \eta_i, \eta_{-i}) = (c_0, c_0, 0, 0)\ \forall\ i$.

We are now in a position to construct and study the critical discount factor as defined in (4). However, due to the tedious expressions for the profits we will not provide a complete exposition and characterization of this threshold. Note that the individual thresholds $\widehat{\delta}_i(a_i, a_{-i}, \eta_i, \eta_{-i})$ defined in (4) are implicit functions of $(a_1, a_2, \eta_1, \eta_2)$, as are the profits.

Equipped with this framework, we next proceed to the analysis of the sustainability of price collusion. We focus on the effect of the asymmetry parameter (influencing the demand elasticity and/or network size) on the incentives for operators to collude. In particular, we examine how asymmetric regulation of the access charge affects the sustainability of collusion. However, a complete analysis for all values of access charges (a_1, a_2) and asymmetry parameters (η_1, η_2) involves strong nonlinearities that make the analysis very tedious. Hence as is common in the literature ,[9] we will analyze asymmetric regulation locally around cost-based access fees. That is, we will study how a departure from cost-based regulation will affect the sustainability of collusion, depending on the potential asymmetry of the networks and the regulation, allowing for reciprocal or asymmetric access charges.

The table 2 summarizes the analysis we conduct hereafter, and it emphasizes that instead of asymmetric regulation, we may as well think of an asymmetric (marginal) cost difference between the networks under symmetric regulation. More precisely, not only do we model asymmetric regulation under symmetric cost or symmetric regulation under asymmetric cost but also (because it is only the net magnitude that matters) the full continuum of cases in-between. This is of importance as it is well known (see for example Ivaldi *et al.* (2007)) that low-cost firms in the industry have less incentives to collude and that cost asymmetry inhibits tacit collusion. This leads to the conventional doctrine that 'it is easier to collude among equals' when costs are considered.

INSERT TABLE 2 here

To better isolate the effect of network asymmetry, we start by assuming that the networks are symmetric, so that $\eta_1 = \eta_2 = 0$, and study the impact of different regulatory access charge regimes (reciprocal *v.s.* asymmetric regulation) on collusion.

[9]Local analysis is used by Peitz (2005) and Baranes and Vuong (2012b) among others. The presence of a European glide path justifies a focus on the neighbourhood of cost-based access charges. With a more mature industry than pre 2005, following following the Gruber (2005) study one may argue that important asymmetries have been eroded by now, partly by regulation such as by requiring number portability.

4 Symmetric networks

This section analyzes the effects of asymmetric regulation,[10] $a_1 \geq a_2 = c_0$, for the case that networks are symmetric, $\eta_1 = \eta_2 = 0$. We first examine reciprocal regulation and then asymmetric regulation.

4.1 Reciprocal regulation as a benchmark

Considering reciprocal regulation, $a_1 = a_2 = a$, with symmetric networks and a cost-based access charge $a = c_0$, it can be shown from (4) that the critical discount factor becomes

$$\hat{\delta}\left(c_0, c_0, 0, 0\right) = \frac{2v(2c_0, 0) - 3\theta}{2v(2c_0, 0) + 5\theta}$$

Note that this corresponds to the long-run situation in which the initial advantages of the incumbent (which may result from brand recognition or switching costs) are overcome and the networks' access charges are regulated to follow, for example, the so-called glide path to cost as implemented by the European Commission.

The critical discount factor $\widehat{\delta}$ is then decreasing with the transportation cost θ, which plays the role of a network differentiation parameter. If θ is larger, goods become less substitutable for consumers, i.e. product differentiation is higher, which implies that it is easier to sustain collusion. Why is this the case? Omitting arguments the competitive profit is $\pi_i^* = \theta/2$ and, as usual in the Hotelling model, it is strongly increasing in θ. Note also that whenever condition (2) holds, there is an incentive to deviate[11] as:

$$\pi_i^D = \frac{\left(2v(2c_0, 0) + \theta\right)^2}{32\theta} \geq \pi_i^* = \frac{\theta}{2}.$$

The collusive profit becomes:

$$\pi_i^C = \frac{2v\left(2c_0, 0\right) - \theta}{4}.$$

Note that the collusive profit is decreasing in θ, i.e. a higher degree of product differentiation reduces the total profit of an already colluding cartel, whereas the effect on the deviation profit is ambiguous. However, the differences in the numerator $\pi_i^D - \pi_i^C$ and the denominator $\pi_i^D - \pi_i^*$ are decreasing in θ and, from the overall result, we know that the effect of the numerator dominates making deviation from the collusive agreement less attractive.

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[10]Since networks are assumed to be symmetric we could either consider the case $a_1 \geq a_2 = c_0$ or $a_2 \geq a_1 = c_0$.

[11]For $\theta = \frac{2}{3}v(2c_0, 0)$ we have $\pi_i^D = \frac{1}{3}v(2c_0, 0)$ and $\pi_i^C = \frac{1}{3}v(2c_0, 0)$ but also $\pi_i^* = \frac{1}{3}v(2c_0, 0)$ then $\delta_i^* = 0$ and one can sustain collusion for any discount factor.

Considering now reciprocal regulation, $a_1 = a_2 = a$, we have the following result.

Proposition 1. *Assume that networks are symmetric. With cost-based regulation, reciprocal access markups facilitate collusion.*

In a symmetric network setting, the critical discount factor $\widehat{\delta}$ is decreasing in the reciprocal access charge. We therefore find that increasing a reciprocal access charge locally around cost facilitates collusion. An access markup exhibits a facilitating-effect with respect to collusion. Conversely, reducing reciprocal access charges towards cost, as under the European glide path will make collusion harder to sustain. This first result underlines the collusive effect of reciprocal regulation in an infinitely repeated tariff competition game and confirms results of the standard literature on competition between interconnected networks stated by Laffont *et al.* (1998a) and Armstrong (1998). Indeed, when the access charge increases from its cost-base, off-net prices reach a higher level for both operators due to reciprocal access charges. Then operators compete through fixed fees which reduces their competitive profits. As a consequence, they have a higher incentive to collude. This proposition shows that following the European glide path yields a double-dividend for welfare when networks are (or have become) symmetric: more allocative efficiency and less collusion threats.

4.2 Asymmetric regulation

We now consider asymmetric regulation, i.e. non-reciprocal access charges $a_1 \geq c_0$ and $a_2 = c_0$. Operators then do not have the same incentives to collude and their critical discount factors take different values: $\widehat{\delta}_1 \neq \widehat{\delta}_2$, even though networks are fully symmetric. Of course such access charges will have an impact on the incentive to collude for both networks and thus on the critical discount factor $\hat{\delta}$. Assume $a_2 = c_0$. The following proposition states the result for a slight deviation of network 1's access charge from its cost-based level. Define $\tilde{\theta} \equiv \frac{6}{13} v(2c_0, 0)$ a threshold level for the transportation cost. Then we find that:

Proposition 2. *Assume that networks are symmetric. In case of asymmetric cost-based regulation, tacit collusion will be facilitated by an access markup if and only if θ is above some threshold $\tilde{\theta}$.*

When networks are symmetric, asymmetric regulation will facilitate collusion whenever product differentiation is sufficiently high. Conversely, reducing asymmetric regulation towards a glide path regime will make collusion harder to sustain. However, this is no longer the case when product differentiation is low. Then competition in fixed charges is fierce, the effect of asymmetric regulation is diluted, and an increasing wedge between on-net and off-net access margins will improve competitive and deviation profits relative to collusive ones. Therefore an increase in the access charge will make collusion harder to sustain.

Indeed, this contrasting result is produced by the combination of two trends within the collusion game. Firstly, product differentiation plays a role. As we have seen above with symmetric regulation, when goods are weak substitutes for consumers, collusion is easier to sustain: higher product differentiation facilitates collusion. Secondly, when asymmetric regulation applies, the disadvantaged firm (here firm 2) may find it profitable to break a collusive agreements as the gains from deviation are increased because of a rise in operating charges. Hence, a wedge between on-net and off-net access prices hinders collusion. Consequently, when product differentiation is low, the effect of asymmetric regulation dominates whereas the effect of product differentiation does, when product differentiation is higher. This discussion is illustrated in Figure 2 below. When product differentiation is low, the gray curve depicts a rise in the critical discount factor with respect to the non-reciprocal access margin. When product differentiation is high, the critical discount factor is depicted by the black curve,[12] it is decreasing.

INSERT FIGURE 2 here

5 Asymmetric networks

We now allow for asymmetric networks with differing asymmetry parameters. Suppose that network 1 now has a higher value of the asymmetry parameter and network 2 still has the lower (previously symmetric) value η_0, so that $\eta_1 > \eta_2 = 0$. Different cases may arise depending on whether network 1 benefits from asymmetric regulation or not. As in the previous section we assume that asymmetric regulation benefits network 1 so $a_1 > a_2 = c_0$. Following Assumptions *A.1* or *A.2*, illustrated by *Examples* 1 and 2, the asymmetry between networks can represent two kinds of situations. Firstly, the network asymmetry may fall fully on the demand elasticity (Assumption *A.1*). In this case, asymmetric regulation benefits the network with the higher elasticity.

It has often been taken for granted that new entrants in the mobile market face a higher elasticity than incumbents because of switching costs or first mover advantages. Asymmetric regulation can then be considered as a way to reduce the

[12]The dashed black (resp. gray) curve depicts the minimal of both discount factors when θ is low (resp. high).

competitive disadvantage of the high elasticity network (i.e. new entrant) by offering the possibility of charging a higher access charge than the incumbent. This has been allowed for in the European regulation of mobile termination rates. Network asymmetry may however also fall on the demand or network size (Assumption *A.2*). This second case thus represents a situation in which asymmetric regulation benefits the operator with the larger demand or network. Such a kind of asymmetric regulation never happened in the access charge regulation policy. This is probably because asymmetric regulation has always been implemented to limit the advantage of the incumbent and favour competition of new entrants.[13] However, asymmetric regulation does have an effect on the sustainability of collusion when favoring the incumbent as asymmetric regulation can reduce the operators' incentives to stick to a collusive agreement. In the following, we investigate how the critical discount factor is affected by both network asymmetry and different regulatory regimes.

5.1 Reciprocal regulation

Assume first that reciprocal regulation applies. Access charges are then cost-based and $a_1 = a_2 = c_0$. The critical discount factors for network i follows.

$$\hat{\delta}_i\left(c_0, c_0, \eta_i, \eta_{-i}\right) = \frac{9\left(v(2c_0, \eta_i) + 3v(2c_0, \eta_{-i}) - 6\theta\right)^2}{\left(23v(2c_0, \eta_i) - 11v(2c_0, \eta_{-i}) + 30\theta\right)\left(7v(2c_0, \eta_i) + 5v(2c_0, \eta_{-i}) - 18\theta\right)} \quad (5)$$

The next result compares the incentive for collusion of both networks and presents the critical discount factor $\widehat{\delta}$.

Lemma 4. *Assuming a small asymmetry between networks (η_1 is in a right neighbourhood of $\eta_2 = 0$):*

(i) if A.1 holds, then $\hat{\delta}_1 > \hat{\delta}_2$ and $\hat{\delta}_1$ is increasing in η_1,

(ii) if A.2 holds, then $\hat{\delta}_1 < \hat{\delta}_2$ and $\hat{\delta}_2$ is increasing in η_1.

When networks are asymmetric and the reciprocal access charge is cost-based, the critical discount factor is that belonging to the operator who, because of a (perceived) difference in networks or the installed user base, is structurally able to lower the consumer's surplus at each price. This finding implies that the more disadvantaged firm is more likely to break a collusive agreement, i.e. its relative optimal deviation profits are higher. This is in line with the common precept that collusion is easier to sustain among equals and conversely, more network asymmetries

[13] Indeed one could imagine that when *A.2* holds, the empirically more plausible case would be that the smaller network is allowed a higher access charge (i.e. $a_2 > a_1$). However, this constellation then creates the same 'mirror empirical' problem if *A*.1 holds.

hinder tacit collusion. Figure 3 illustrates these results: the critical discount factors for disadvantaged firms are shown to be increasing with respect to the asymmetry η_1. When surplus and demand are depressed by this asymmetry, firm 1 is disadvantaged (black thick curve); when they are inflated, it is firm 2 that is disadvantaged (gray thick curve).

INSERT FIGURE 3 here

Let us now assume reciprocal access charges, $a_1 = a_2 = a \geq c_0$, and a small access charge mark-up. In Proposition 3 below we focus on the interplay between network asymmetries and reciprocal access charges. Remember that in a symmetric network under reciprocal regulation an increase in the access charge above cost facilitates collusion, the facilitating-effect from Proposition 1. Let us define $\varepsilon_v = -v_2(p, \eta)v(p, \eta)/(1 + \eta)$ the elasticity of the surplus with respect to the asymmetry η and by analogy, $\varepsilon_q = -q_2(p, \eta)q(p, \eta)/(1 + \eta)$, the elasticity of the demand. These asymmetry elasticities indicate how these fundamentals vary relatively to an relative increase in the asymmetry parameter. We now find:

Proposition 3. *With asymmetric networks and reciprocal regulation with access charges above cost, the effect of network asymmetries on the facilitating-effect is ambiguous. If A.2 holds, the facilitating-effect is unambiguously amplified. This is also the case when A.1 holds for multiple configurations. When A.1 holds the effect is weakened however, if around* $(p, \eta) = (2c_0, 0)$ *the ratio of elasticities* $\varepsilon_v/\varepsilon_q$ *is below a given threshold and the transportation cost parameter* θ *is within an interval.*

As shown in Proposition 1 with homogeneous networks, reciprocal access charges above cost exhibit a facilitating-effect for collusion in the industry. Proposition 3 shows that this facilitating-effect is not always enhanced further by network asymmetries. In case the asymmetry has a strong impact on demand elasticity (i.e. when *A.1* holds) the effect depends on both the level of product differentiation and the impact of network asymmetries on surplus and demand. It is worth pointing out that depending on those fundamentals, the critical discount factor can be reduced when the reciprocal access charge is slightly raised above cost: more asymmetries do not systematically inhibit collusion, but this will be the case when asymmetries markedly deteriorate surpluses and demands but in a low relative magnitude, i.e. $\varepsilon_v/\varepsilon_q$ is below a given threshold γ. This is illustrated in Figure 4. The light-gray shaded area represents values of the ratio of elasticities $\varepsilon_v/\varepsilon_q$ and the transportation cost θ for which the facilitating-effect of reciprocal access is weakened by network asymmetries. For instance, consider that the ratio of elasticities $\varepsilon_v/\varepsilon_q$ is set at the level γ_0, depicted by the dashed horizontal line. When the transportation cost is in the interval $[\theta_1, \theta_2]$ the facilitating-effect is weakened but it is amplified elsewhere.

INSERT FIGURE 4 Here

For the case that the asymmetry impacts mostly on network scale (i.e when *A.2* holds), we get a clear cut result. We already know that it is the disadvantaged firm that has the stronger incentives to deviate. We now see that a further increase in this scale asymmetry will amplify the negative impact of an increasing wedge on competitive profits, thus increasing the severity of punishment, making deviation less attractive.

5.2 Asymmetric regulation

Finally we now consider the most general situation of asymmetries on both the regulatory and the network side. From Proposition 2 we know the effects of non-reciprocal access margins on collusion (around cost-based pricing) and from Proposition 3 we have results on the effects of network asymmetries. Using these findings we now investigate how the possibilities of sustaining collusion are affected by slight network asymmetries when non-reciprocal access charges are set by the regulator, *i.e.* $a_1 \geq c_0$ and $a_2 = c_0$,. Remembering that a threshold level for the transportation cost, $\tilde{\theta} = \frac{6}{13}v(2c_0, 0)$ has been defined above, one can state:

Proposition 4. *With asymmetric networks and asymmetric regulation, the effect of network asymmetries on the facilitating-effect is ambiguous. (i) If* A.2 *holds and when* $\theta \geq \tilde{\theta}$, *the facilitating-effect is unambiguously amplified. (ii) If A.1 holds, there exists a new threshold level of the transportation cost parameter* $\tilde{\tilde{\theta}} > \tilde{\theta}$, *such that, above this threshold the facilitating-effect is amplified and weakened otherwise.*

Also in case of reciprocal access regulation, slight network asymmetries have various effects on the firms' ability to collude, that can be exacerbated or dampened by a non-reciprocal access regulation.

When the network asymmetries reduce the surplus and demand, that is when *A.2* holds, the disadvantaged firm (here firm 2) is *even more* disadvantaged as access charges it has to bear increases. However, when products are strong substitutes, the effect of a low product differentiation dominates and we have already seen in Proposition 2 that such an access markup inhibits collusion. Up to this effect, the network asymmetry amplifies this inhibiting result. Conversely, when products are weak substitutes, the effect of asymmetric regulation dominates, it facilitates collusion and the network asymmetry amplifies the facilitating-effect of positive off-net access markups on collusion.

When the network asymmetries inflate surplus demand, that is when *A.1* holds, a positive off-net access markup is always facilitating collusion. Indeed in this configuration, the disadvantaged firm (here firm 1) is *even less* disadvantaged as the off-net access charge increases, as it corresponds to a unit revenue. The impact of asymmetric regulation is of first order for any level of product differentiation. However, a slight network asymmetry strengthens this facilitating-effect on collusion if product differentiation is high but weakens this effect otherwise. That is the effect of product differentiation is only of second order: When products are strong substitutes, an off-net access markup just reduces the increase in the gain from deviation.

Hence, in both cases, if product differentiation is high enough, more asymmetries do not inhibit collusion. Thus, the case where the asymmetry impacts mostly on the network scale is analogous to the case with symmetric regulation.

Figure 5 illustrates Proposition 4. It shows how network asymmetries modify the relevant discount factors when the access price a_1 increases. Dashed curves are those already depicted in Figure 2 and plain curves are those obtained when asymmetry applies. Arrows identify the effect of the off-net access markup on the way the discount factor is varying.

INSERT FIGURE 5 Here

6 Conclusion

For a differentiated Bertrand duopoly setting, Baranes and Poudou (2009) show that cost symmetry may inhibit collusion, so that the common precept that it is easier to collude amongst equals does not always hold. In this paper, we look at a differentiated Hotelling duopoly model of the kind used by Laffont *et al.* (1998a,b) for the telecommunications industry with a potential asymmetry from differences in demand elasticities and/or installed bases that may result from differences in firm histories.

The technical breakthroughs in this industry have started in the beginning of this century. Once these have lead to a long-run competitive outcome rendering networks homogeneous, a cost-based access pricing regime implies that a large reciprocal on-net off-net margin will actually improve the possibilities for collusion. We also find that reducing reciprocal access charges towards true cost, as aimed at by the European glide path envisaged by the Commission - and Ofcom in the UK, (see Ofcom, 2010)- will make collusion harder to sustain for homogenous networks. Hence this policy can be seen to yield a double-dividend.

In a competitive setting with heterogeneous networks, i.e. what can be seen as the medium term outcome, where competition will have fostered and regulation can therefore be relaxed, a higher degree of differentiation in demand elasticities actually improves firms' profits and it is the firm facing the larger demand elasticity (usually the incumbent) that is more likely to have a level of impatience that leads to the breach of a collusive agreement. This has implications for medium term policy, as measures aimed at equalizing (consumers' perceptions of the) networks may actually improve firms' possibilities for collusion. The finding is thus in line with the common precept that it is easier to sustain collusion amongst equals, and should keep regulators on their toes.

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Appendix

• **Proof of Lemma 1.** Given in Laffont *et al.* (1998b). This allows us to write the equilibrium competitive profits for $i = 1, 2$:

$$\begin{aligned}\pi_i^* \left(a_i, a_j, \eta_i, \eta_j\right) \quad = \quad & \frac{2\theta + \Sigma_{k=1}^{k=2} V_{kk}\left(\widehat{p}_i^*, p^*\right) + R_{-i}\left(a_i, c_0, \hat{p}_j^*\right)}{\left(6\theta + 2\Sigma_{k=1}^{k=2} R_k\left(a_{-k}, c_0, \hat{p}_k^*\right) + 3\Sigma_{k=1}^{k=2} V_{kk}\left(\widehat{p}_k^*, p^*\right)\right)^2} \\ & \times \left(3\theta + 2V_{i(-i)}\left(\widehat{p}_i^*, p^*\right) + V_{(-i)i}\left(\widehat{p}_{-i}^*, p^*\right) + \Sigma_{k=1}^{k=2} R_k\left(a_{-k}, c_0, \hat{p}_k^*\right)\right)^2\end{aligned}$$

■

• **Proof of Lemma 2.** Using (3), one can form the joint profit $\pi_1(\mathbf{p}, \mathbf{w}) + \pi_2(\mathbf{p}, \mathbf{w})$ and show that *(ii)* is independent of (a_1, a_2), so that the relevant first order conditions

$$\frac{\partial(\pi_1(\mathbf{p}, \mathbf{w}) + \pi_2(\mathbf{p}, \mathbf{w}))}{\partial p_i} = 0, \frac{\partial(\pi_1(\mathbf{p}, \mathbf{w}) + \pi_2(\mathbf{p}, \mathbf{w}))}{\partial \hat{p}_i} = 0 \ \forall i \in \{1, 2\}$$

imply $p_1^C = \hat{p}_1^C = 2c_0$. Then from $\hat{x} = (\theta + w_1 - w_2)/2\theta$ we have that

$$\hat{x} = \alpha = \frac{1}{2} + \frac{w_1 - w_2}{2\theta}$$

and with (1) using $\mathbf{p}^C$ we can calculate

$$\hat{\alpha}^C = \frac{1}{2} + \frac{1}{2\theta}(v(2c_0, \eta_1) - f_1 - v(2c_0, \eta_2) + f_2)$$

Setting the utility of the marginal consumer to zero,

$$\hat{U} = \hat{\alpha}^C v(2c_0, \eta_1) + (1 - \hat{\alpha}^C) v(2c_0, \eta_2) - f_1 = 0$$

we can determine the collusive fixed charge:

$$f_1^C = v(2c_0, \eta_1) + v(2c_0, \eta_2) - f_2 - \theta$$

Putting this into $\Pi = \pi_1(\mathbf{2c}_0, \mathbf{w}) + \pi_2(\mathbf{2c}_0, \mathbf{w})$ and maximizing it w.r.t. f_2, s.t. $U_2(\alpha_1^C) \geq 0$, yields

$$\mathbf{f}^C = \begin{pmatrix} f_1^C \\ f_2^C \end{pmatrix} = \frac{1}{4} \begin{pmatrix} 3v(2c_0, \eta_1) + v(2c_0, \eta_2) - 2\theta \\ 3v(2c_0, \eta_2) + v(2c_0, \eta_1) - 2\theta \end{pmatrix}.$$

Using this solution, we obtain the collusive profit of network i as:

$$\pi_i^C(a_i, a_{-i}, \eta_i, \eta_{-i}) = \frac{\left(2\theta + V_{i(-i)}\left(p^C, p^C\right)\right)\left(2\theta + V_{(-i)i}\left(p^C, p^C\right)\right)}{16\theta^2} \times \left(R_{-i}\left(a_i, c_0, p^C\right) - R_i\left(a_{-i}, c_0, p^C\right) + \frac{\theta\left(3v\left(p^C, \eta_i\right) + v\left(p^C, \eta_{-i}\right) - 2\theta\right)}{\left(2\theta + V_{i(-i)}\left(p^C, p^C\right)\right)}\right)$$

■

• **Proof of Lemma 3**. W.l.o.g. assume that $i = 1$. A similar proof holds if $i = 2$. From (3) the relevant first order conditions

$$\frac{\partial(\pi_1\left(p_1, \hat{p}_1, p_2^C, \hat{p}_2^C, f_1, f_2^C\right))}{\partial p_1} = 0 \text{ and } \frac{\partial(\pi_1\left(p_1, \hat{p}_1, p_2^C, \hat{p}_2^C, f_1, f_2^C\right))}{\partial \hat{p}_1} = 0$$

imply

$$\left(p_1^D, \hat{p}_1^D\right) = (p_1^*, \hat{p}_1^*) = (2c_0, c_0 + a_2)$$

i.e. optimal deviation yields 'perceived marginal cost' pricing just as in monopoly. The deviant profit given $\left(p_1^D, \hat{p}_1^D\right)$ is

$$\pi_1^D = \hat{\alpha}^D\left((1 - \hat{\alpha}^D)\hat{q}_2(a_1 - c_0) + f_1^D\right)$$

and thus

$$f_1^D = \frac{\pi_1^D}{\alpha_1^D} - (1 - \alpha_1^D) q(\hat{p}_2^C, \eta_2)(a_1 - c_0)$$

with $\hat{p}_2^C = 2c_0 = p^*$. Moreover as $\hat{x} = \alpha$ with (1) and using $\left(p_1^D, \hat{p}_1^D\right)$, we can calculate

$$\hat{\alpha}^D = \frac{\theta - f_1 + f_2 - v(2c_0, \eta_2) + v(c_0 + a_2, \eta_1)}{2\theta - v(2c_0, \eta_1) + v(c_0 + a_2, \eta_1)}$$

Setting the utility of the marginal consumer to zero

$$\hat{U} = \hat{\alpha}^D v(2c_0, \eta_1) + (1 - \hat{\alpha}^D) v(c_0 + a_2, \eta_2) - f_1 - \theta\hat{\alpha}^D = 0$$

this can be solved for

$$f_2 = \frac{\theta f_1 + (\theta - v(2c_0,\eta_1) - v(2c_0,\eta_2)\theta - v(c_0+a_2,\eta_1)v(2c_0,\eta_2) + v(2c_0,\eta_1)v(2c_0,\eta_2)}{v(2c_0,\eta_1) - v(c_0+a_2,\eta_1) - \theta}.$$

Plugging this into the deviant profit

$$\pi_1^D = \hat{\alpha}_1^D \left((1-\hat{\alpha}_1^D)\hat{q}_2(a_1-c_0) + f_1^D\right)$$

and maximizing over f_1, one finds the optimal deviation profit for network 1,

$$\pi_1^D(a_1,a_2,\eta_1,\eta_2) = \frac{1}{64}\frac{\left(4\,v(\hat{p}_1^*,\eta_1) + 4R_2(a_1,c_0,\hat{p}_2^*) + V_{12}(p^*,p^*) + 2\,\theta\right)^2}{R_2(a_i,c_0,\hat{p}_2^*) + V_{11}(\hat{p}_1^*,p^*) + 2,\theta},$$

the symmetric for network 2. Note that when firms are homogeneous and access prices are cost-based,

$$\hat{\alpha}_1^D = \frac{2v(2c_0,0)+\theta}{8} = 1-\hat{\alpha}_2^D.$$

It can be straightforwardly checked that $\hat{\alpha}_i^D \in [0,1]$ if (2) holds. ■

• **Proposition 1:** Using $\hat{\delta}_i = (\pi_i^D - \pi_i^C)/(\pi_i^D - \pi_i^*)$ with the profit terms for homogenous firms and reciprocal non cost-based access charges we take the derivative with respect to a and replace the access charge with the true cost term c_0, to find

$$\lim_{a\to c_0}\frac{\partial\hat{\delta}(a,a,0,0)}{\partial a} = -8\theta\frac{q(2c_0,0)}{(2v(2c_0,0)+5\theta)^2} < 0.$$

■

• **Proof of Proposition 2.** Denote the difference between both individual critical discount factors by $\Delta(a_1,a_2,\eta_1,\eta_2) \equiv \hat{\delta}_1(a_1,a_2,\eta_1,\eta_2) - \hat{\delta}_2(a_2,a_1,\eta_2,\eta_1)$. Around the point of cost-based access pricing for a_2, the variation of the difference between the critical discount factor $\hat{\delta}_1 - \hat{\delta}_2$ w.r.t. a_1 evaluated for $a_1 = c_0$ is

$$\lim_{a_1\to c_0}\frac{\partial\Delta(a_1,c_0,0,0)}{\partial a_1} = -\frac{16}{3}\frac{q(2c_0,0)(3v(2c_0,0)-5\theta)}{(2v(2c_0,0)+5\theta)^2}.$$

It is positive if $\theta \geq \frac{3}{5}v(2c_0,0)$ but negative if $\theta < \frac{3}{5}v(2c_0,0)$. Hence if $\theta \geq \frac{3}{5}v(2c_0,0)$, as $\hat{\delta}_1 = \max\{\hat{\delta}_1,\hat{\delta}_2\}$, it is the relevant critical discount factor. Taking the derivative with respect to a_1 for $a_1 = c_0$ leads to

$$\frac{\partial\hat{\delta}_1(c_0,c_0,0,0)}{\partial a_1} = -\frac{4}{3}\frac{q(2c_0,0)(6v(2c_0,0)-7\theta)}{(2v(2c_0,0)+5\theta)^2} < 0\ \forall\theta.$$

For $\theta < \frac{3}{5}v(2c_0,0)$ the relevant critical discount factor is then $\hat{\delta}_2$ and the derivative with respect to a_1 for $a_1 = c_0$ is

$$\frac{\partial\hat{\delta}_2(c_0,c_0,0,0)}{\partial a_1} = \frac{4}{3}\frac{q(2c_0,0)(6v(2c_0,0)-13\theta)}{(2v(2c_0,0)+5\theta)^2} \lesseqgtr 0 \text{ if } \theta \gtreqless \tilde{\theta}.$$

where $\tilde{\theta} = \frac{6}{13} v(2c_0, 0)$. ■

• **Proof of Lemma 4.** Let us consider $(a_1, a_2, \eta_1, \eta_2) = (c_0, c_0, \eta_1, 0)$. From (5), can be derived:

$$\begin{aligned} \hat{\delta}_1 (c_0, c_0, \eta_1, 0) &= 9 \frac{(3\nu^0 + \nu^1 - 6\,\theta)^2}{(7\nu^1 + 5\nu^0 - 18\,\theta)(23\nu^1 - 11\nu^0 + 30\theta)} \\ \hat{\delta}_2 (c_0, c_0, 0, \eta_1) &= 9 \frac{(3\nu^1 + \nu^0 - 6\,\theta)^2}{(7\nu^1 + 5\nu^0 - 18\,\theta)(23\nu^1 - 11\nu^0 + 30\theta)} \end{aligned}$$

where $\nu^0 = v(2c_0, 0)$ and $\nu^1 = v(2c_0, \eta_1)$. Thus we can form $\Delta(c_0, c_0, \eta_1, 0) = \hat{\delta}_1 (c_0, c_0, \eta_1, 0) - \hat{\delta}_2 (c_0, c_0, 0, \eta_1)$ and consider a slight increase in η_1 above 0. Then we have

$$\frac{\partial \Delta (c_0, c_0, 0, 0)}{\partial \eta_1} = -\frac{16}{3} v_2(2c_0, 0) \frac{3\nu^0 - \theta}{(2\nu^0 + 5\theta)^2}. \tag{A.1}$$

As θ has been assumed to take values below $\frac{2}{3}\nu^0$, the sign of this derivative is exactly the opposite of the sign of $v_2(p, \eta)$. Hence it depends on assumptions *A.1* and *A.2*. Finally, if then *A.1* holds, $\frac{\partial \hat{\delta}_1 (c_0, c_0, 0, 0)}{\partial \eta_1} = -\frac{8}{3}(3\nu^0 - 4\theta) v_2(2c_0, 0)/((2\nu^0 + 5\theta)^2) > 0$. If *A.2* holds: $\frac{\partial \hat{\delta}_2 (c_0, c_0, 0, 0)}{\partial \eta_1} = \frac{8}{3}(3\nu^0 + 2\theta) v_2(2c_0, 0)/((2\nu^0 + 5\theta)^2) > 0$. ■

• **Proof of Proposition 3.** If *A.1* holds, i.e. $v_2(p, \eta) < 0$ and $q_2(p, \eta) < 0$, the following second order cross-partial derivative tells us how this reciprocal access pricing effect is modified by an increase in network asymmetry, that is

$$\frac{\partial^2 \hat{\delta}_1 (c_0, c_0, 0, 0)}{\partial a \partial \eta_1} = \frac{4}{3} \frac{(6\nu^0 - 13\theta)}{(2\nu^0 + 5\theta)^2} q_2 - \frac{8}{9} \frac{(8(\nu^0)^2 - 154\theta\nu^0 + 117\theta^2)\, q^0}{(2\nu^0 - 3\theta)(2\nu^0 + 5\theta)^3} v_2$$

with $\nu^0 = v(2c_0, 0)$, $q^0 = q(2c_0, 0)$, $v_2 = v_2(2c_0, 0)$ and $q_2 = q_2(2c_0, 0)$. Letting $\theta = xv^0$ for $x \leq \frac{2}{3}$, one first can see easily see that $(8 - 154x + 117x^2)(v^0)^2 < 0$ if (2) holds, i.e. if $x \in [\frac{2}{7}, \frac{2}{3}]$. Hence if $x \in [\frac{2}{7}, \frac{6}{13}]$ then unambiguously (omitting arguments) $\partial^2 \hat{\delta}_1 / \partial a \partial \eta_1 < 0$. However if $x > \frac{6}{13}$, we can find values $\underline{y}(x)$ of $\frac{v_2}{q_2}$ such that $\partial^2 \hat{\delta}_1 / \partial a \partial \eta_1$ reaches zero for each $x \in]\frac{6}{13}, \frac{2}{3}]$. This leads to solving $\partial^2 \hat{\delta}_1 / \partial a \partial \eta_1 = 0$ with respect to $\frac{v_2}{q_2}$, that is

$$\underline{y}(x) = \frac{3}{2} \frac{(6 - 13x)(2 - 3x)(2 + 5x)}{8 - 154x + 117x^2} \frac{\nu^0}{q^0} > 0 \ \forall \ x \in]\frac{6}{13}, \frac{2}{3}].$$

Moreover studying $\underline{y}(x)$ shows that in the interval $]\frac{6}{13}, \frac{2}{3}]$, it reaches its maximum for $x = \underline{x}$ where $\underline{y}'(\underline{x}) = 0$ for

$$\underline{x} \in \arg \left\{ x \in]\frac{6}{13}, \frac{2}{3}] \middle| 3472 - 7888x + 29824x^2 - 60060x^3 + 22\,815x^4 = 0 \right\}$$

so that $\underline{x} \simeq 0.5568$ and $\underline{y}(\underline{x}) \simeq 0.107 \frac{\nu^0}{q^0} > 0$. Therefore we can conclude that if $\frac{v_2}{q_2} > \underline{y}(\underline{x})$ we have $\partial^2 \hat{\delta}_1 / \partial a \partial \eta_1 < 0$ for all admissible x. But if $\underline{y}(\underline{x}) > \frac{v_2}{q_2} > 0$, as $\partial^2\hat{\delta}_1/\partial a\partial\eta_1$ increases with v_2, we have $\partial^2\hat{\delta}_1/\partial a\partial\eta_1 > 0$ at $x = \underline{x}$. As $\underline{y}(x)$ is strictly concave in x, for each v_2 there exist two values of $\underline{x}_1$ and $\underline{x}_2$ such that $\underline{x}_2 < \underline{x} < \underline{x}_1 < \frac{6}{13}$, defined by $\underline{y}(\underline{x}_1) = \underline{y}(\underline{x}_2) = \frac{v_2}{q_2}$ and for which $\partial^2\hat{\delta}_1/\partial a\partial\eta_1 > 0$ when $x \in [\underline{x}_1, \underline{x}_2]$. Noticing that $\frac{v_2}{q_2} = \frac{\varepsilon_v}{\varepsilon_q}\frac{q}{v}$ yields the result.

Second, assume that *A.2* holds, i.e. $v_2(p,\eta) \geq 0$ and $q_2(p,\eta) \geq 0$. In the same way as above, one finds that

$$\frac{\partial^2\hat{\delta}_2(c_0,c_0,0,0)}{\partial a\partial\eta_1} = -\frac{4}{3}\frac{(6\nu^0 - 7\theta)}{(2\nu^0+5\theta)^2}q_2 + \frac{8}{9}\frac{(8(\nu^0)^2 - 82\theta\nu^0 + 9\theta^2)\,q^0}{(2\nu^0-3\theta)(2\nu^0+5\theta)^3}v_2$$

Letting $\theta = xv^0$ for $x \leq \frac{2}{3}$, one can easily see that $(8x^2 - 82x + 9)\,\theta^2 < 0$ and $(6x-7)\,\theta > 0$ if (2) holds. As a result $\partial^2\hat{\delta}_2/\partial a\partial\eta_1 < 0\ \forall\ x \leq \frac{2}{3}$. ■

• **Proof of Proposition 4.** From Lemma 4 we know that around cost-based access pricing for a slight asymmetry of network 1 such that $\eta_1 > \eta_2 = 0$, the critical factor is $\hat{\delta}_1$ if $v_2(p,\eta) < 0$ and $\hat{\delta}_2$ if $v_2(p,\eta) > 0$. If *A.1* holds, i.e. $v_2(p,\eta) < 0$, the following second order cross-partial derivative tells us how this access pricing effect is modified by an increasing network asymmetry, that is

$$\frac{\partial^2\hat{\delta}_1(c_0,c_0,0,0)}{\partial a_1\partial\eta_1} = -\frac{4}{9}\frac{\left(36\,(v^0)^3 - 188\theta\,(v^0)^2 + 637\theta^2\nu^0 - 718\,\theta^3\right)q^0}{\theta\,(2\nu^0-3\theta)(2\nu^0+5\theta)^3}v_2$$

where $\nu^0 = v(2c_0,0)$, $q^0 = q(2c_0,0)$, $v_2 = v_2(2c_0,0)$. Let $\theta = xv^0$ for $x \leq \frac{2}{3}$. We have $(36 - 188x + 637x^2 - 718x^3)\,(v^0)^3 \geq 0$, and so $\frac{\partial^2\hat{\delta}_1(c_0,c_0,0,0)}{\partial a_1\partial\eta_1} > 0$ if $x \geq x_0 = 0.586$, and is negative otherwise. However, in the Proof of Proposition 2 we have shown that around the point of network symmetry: $\frac{\partial\hat{\delta}_1(c_0,c_0,0,0)}{\partial a_1} < 0$ for all θ. Let $\tilde{\tilde{\theta}} = x_0v_0$, this implies that $\frac{\partial^2\hat{\delta}_1(c_0,c_0,0,0)}{\partial a_1\partial\eta_1} \lesseqqgtr 0$ if $\theta \gtreqqless \tilde{\tilde{\theta}}$. When *A.2* holds i.e. $v_2(p,\eta) \geq 0$, the corresponding derivative of the critical discount factor $\hat{\delta}_2$ is

$$\frac{\partial^2\hat{\delta}_2(c_0,c_0,0,0)}{\partial a_1\partial\eta_1} = -\frac{4}{9}\frac{\left(36\,(v^0)^3 - 132\theta\,(v^0)^2 + 345\theta^2\nu^0 - 214\theta^3\right)q^0}{\theta\,(2\nu^0-3\theta)(2\nu^0+5\theta)^3}v_2$$

Using again the change of variables $\theta = xv^0$ for $x \leq \frac{2}{3}$ we have

$$\left(36 - 132x + 345x^2 - 214^3\right)\left(v^0\right)^3 \geq 0, \forall x,$$

and so $\frac{\partial^2\hat{\delta}_2(c_0,c_0,0,0)}{\partial a_1\partial\eta_1} < 0$. From Proposition 2, we know that $\frac{\partial\hat{\delta}_2(c_0,c_0,0,0)}{\partial a_1} \lessgtr 0$ as $\theta \gtrless \tilde{\theta} = \frac{6}{13}\nu^0$. Then for θ 'large' we have $\frac{\partial\hat{\delta}_2(c_0,c_0,0,0)}{\partial a_1} < 0$ and the critical discount factor is equally reduced further by (slight) network asymmetries. ■

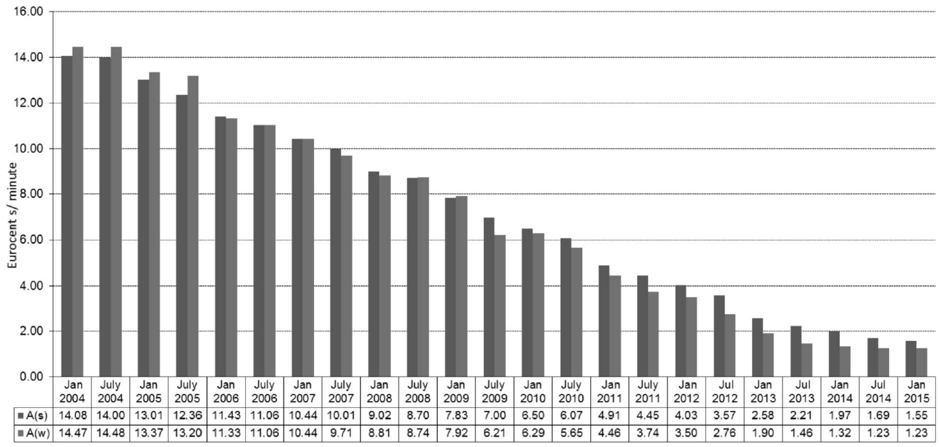

Figure 1: Average MTR time series. Source: BEREC (2015)[14]

<table>
<tr><th>c €/ Years</th><th>2002</th><th>2003</th><th>2004</th><th>2005</th><th>2006</th><th>2007</th><th>2008</th><th>2009b</th><th>2010b</th><th>2011a</th><th>2012a</th><th>2012b</th><th>2013a</th><th>2013b</th><th>2015</th><th>2016</th><th>2017</th></tr>
<tr><td>Orange</td><td rowspan="2">20.12</td><td rowspan="2">17.07</td><td rowspan="2">14.9</td><td rowspan="2">12.5</td><td rowspan="2">9.5</td><td rowspan="2">7.5</td><td rowspan="2">6.5</td><td rowspan="2">4.5</td><td rowspan="2">3</td><td rowspan="3">2</td><td rowspan="3">1.5</td><td rowspan="3">1</td><td rowspan="3">0.8</td><td rowspan="5">0.8</td><td rowspan="5">0.78</td><td rowspan="5">0.76</td><td rowspan="5">0.74</td></tr>
<tr><td>SFR</td></tr>
<tr><td>Bouygues T</td><td>27.5</td><td>24.6</td><td>17.9</td><td>14.8</td><td>11.2</td><td>9.2</td><td>8.5</td><td>6</td><td>3.4</td></tr>
<tr><td>Free Mobile</td><td rowspan="2" colspan="11"></td><td rowspan="2">1.6</td><td rowspan="2">1.1</td></tr>
<tr><td>Full MVNO</td></tr>
</table>

Table 1: Asymmetries and glide paths for MTRs in France. Source: ARCEP (2015), Website[13]

Figures and Tables

[14]Black rectangles are nominal MTRs averages for European operators for each year. Gray rectangles are weighted averages that do not take into account missing data for subscribers and those that have switched.

[13]Year "201xa" corresponds to the first half of 201x, year "201xb" to the second half.

<table>
<tr><td colspan="2"></td><td colspan="2">Cost Asymmetry</td></tr>
<tr><td colspan="2"></td><td>No</td><td>Yes</td></tr>
<tr><td rowspan="2">Network
Asymmetry</td><td>No</td><td>Benchmark</td><td>$\eta_1 = \eta_2$ and $a_1 > a_2$</td></tr>
<tr><td>Yes</td><td>$\eta_1 > \eta_2$ and $a_1 = a_2$</td><td>$\eta_1 > \eta_2$ and $a_1 > a_2$</td></tr>
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Table 2: Dual asymmetric framework.

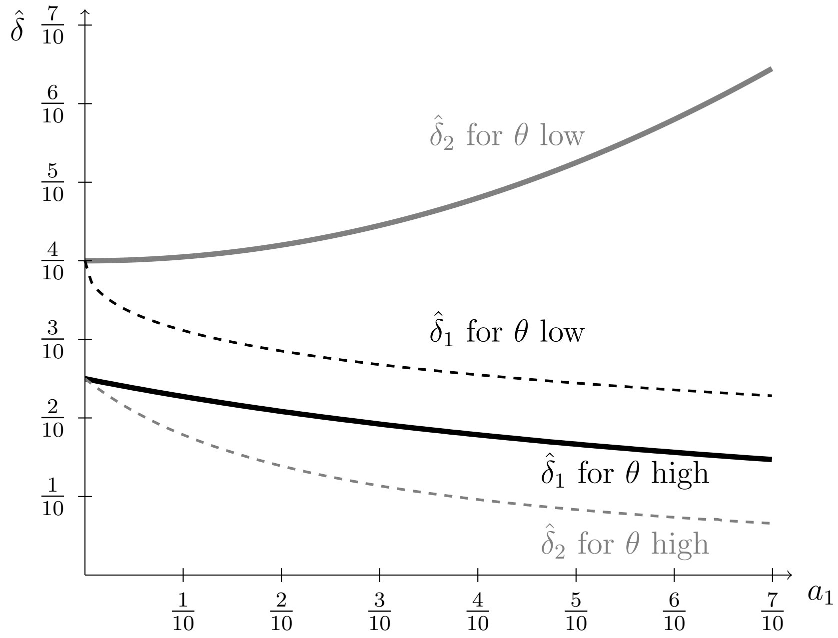

Figure 2: Symmetric network and reciprocal access

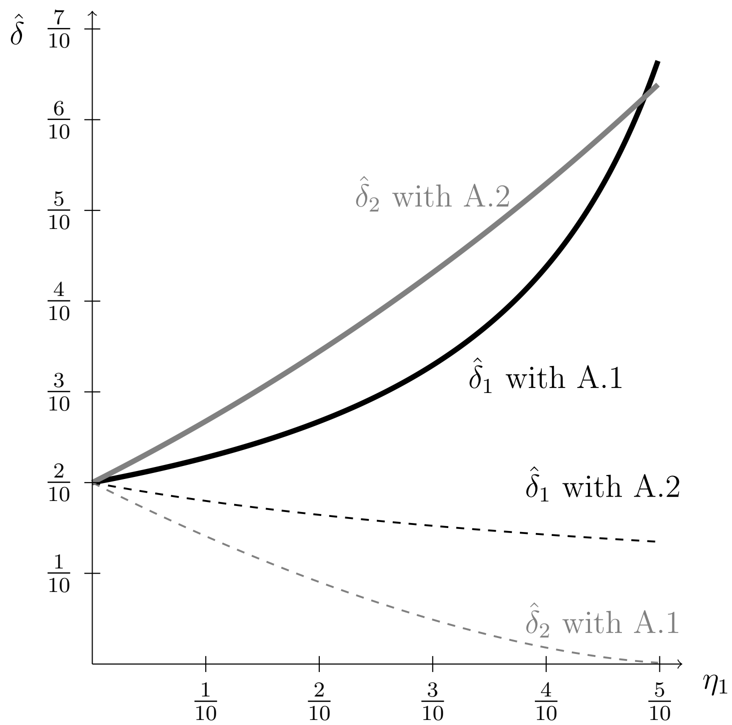

Figure 3: Reciprocal access with asymmetric networks

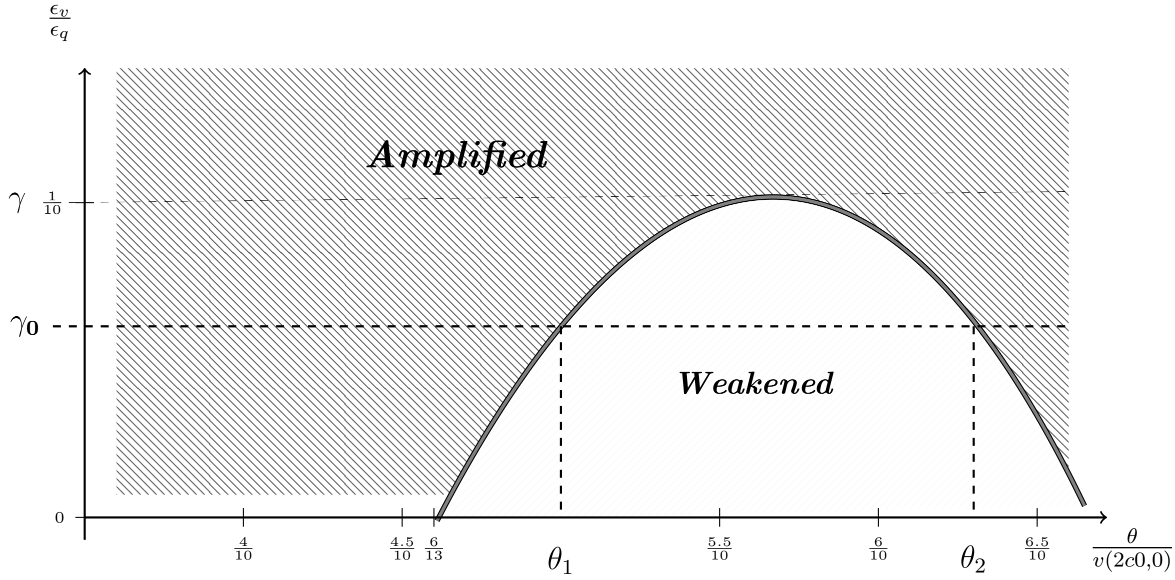

Figure 4: Asymmetric networks: Facilitating effect when *A.1* holds

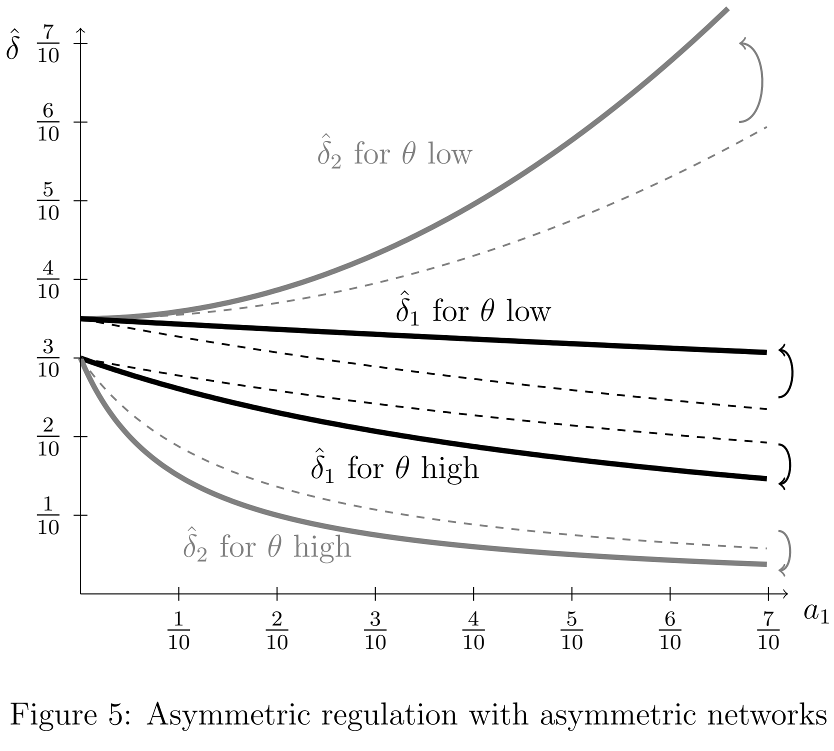

Figure 5: Asymmetric regulation with asymmetric networks