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Abstract

The paper considers the optimal regulation of access charges, and the effect such regulation has on incentives to foreclose downstream rival firms. I show that when a vertically integrated firm is able to discriminate against rivals by means of non-price measures, optimal access charges must be set higher than in the case when no discrimination is possible and will always provide a positive access margin. The reason is that the level of the access charge affects incentives to practice foreclosure. The optimal access charge may, when non-price measures are not possible, be lower than marginal cost of providing access.

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1 Introduction

In vertically related markets, the production of final products makes use of (essential) inputs produced in complementary markets. The producers of these essential inputs usually have opportunities to earn positive economic profits. The extent to which this is possible depends, among other things, both on regulatory and competition policies. In the communications industry, firms offering e.g. Internet access to end-users must purchase access to consumers from local access providers, and the pricing of local access is often subject to regulation.[1] The main reason for regulating access charges is to stimulate competition, by ensuring that rival firms can obtain access to end-users at reasonable terms. This means setting a low access charge. Allowing vertical integration opens up the possibility for foreclosure activities by the vertically integrated firm, by restricting the integrated firm's earning potential upstream results in an increased incentive to foreclose its rivals (as is pointed out by, e.g., Sibley and Weisman, 1998). A combined policy of allowing vertical integration and regulation of the monopoly rent upstream (through access charge regulation) may have an adverse effect on downstream competition. By restricting local access providers' opportunity to serve long-distance markets (i.e., refusing vertical integration), competition authorities may restrict the potential for earning monopoly rent upstream without resorting to the regulation of access charges.[2] This is a result well known in the literature on vertical relations.[3]

The contribution of the present paper to the theory of access charge regulation is to provide an analysis of how the opportunity for foreclosure of independent rivals affects the socially optimal access charges. The foreclosure may be thought of either as degrading the quality of network inputs, or equivalently, as increasing the cost of purchasing such inputs (in addition to the exogenously given access

[1] The local access providers are often the incumbent telecommunications companies.

[2] In the case of U.S. legislation, restrictions are to some extent imposed on which firms are allowed into the long-distance markets. However, in the present paper vertical separation is not considered.

[3] This result is a consequence of the upstream firm's inability to credibly commit to charging monopoly prices (Rey and Tirole, 1997)

price). The increased costs for the rivals could, for instance, be due to legal expenses incurred when attempting to obtain access on equal terms with the network owner's downstream subsidiary, or more direct costs due to lower quality of access.

The access terms offered to rival firms consist of two main elements - the price paid for access and the quality of access. I assume that the access charge is subject to regulation. The issue of access charge regulation has been examined by a number of other authors (e.g., Armstrong, Doyle and Vickers (1996), Laffont and Tirole (1990, 1996)). In contrast to their work, I focus on the relation between the regulated access charge and the vertically integrated firm's incentive to foreclose its rival along other dimensions. The network provider has ample opportunities to degrade the quality of access offered to its competitors. The decision of the network provider (the vertically integrated firm) on access *quality* is *not* regulated in the model, and may affect competition in the downstream market. The incentive to foreclose rival firms in a complementary market segment is considered by, e.g., Economides (1998a,b), Sibley and Weisman (1998), Mandy (2000), Weisman and Kang (2001), Reiffen and Ward (2002), and Beard, Kaserman and Mayo (2001). These authors have all identified the level of the access charge as a determinant for non-price foreclosure. Contrary to their work, the present paper considers an endogenous access charge and investigates how access charges should be set in this context to achieve the social optimum. The issue of raising rivals' costs is the focus of Economides (1998a, 1998b), and his model is extended to incorporate the optimal regulation of access charges.

The issue analysed in the present paper is also related to optimal price regulation when firms provide unverifiable quality, which is dealt with by, e.g., Laffont and Tirole (1991) and Lewis and Sappington (1991). By allowing firms to charge a price in excess of marginal cost, overall efficiency is reduced through a contraction in output. However, a high profit margin results in improved incentives to provide quality, and the efficiency loss from such a pricing policy is balanced by higher quality. In the present paper, the efficiency loss due to pricing access in excess of marginal cost is balanced against the reduction in the efficiency loss from foreclosure.

In the present model, following a partial approach, I assume that the downstream industry is deregulated.[4] This is the case, e.g., in the telecommunications industry. Often, the regulation of access charges is easier to implement than regulation of final product prices due to a vast array of different products on the market. It also seems to be the case that industry regulators focus more of their attention on the regulation of access terms. I also assume that the regulator's toolbox is restricted. Specifically, the regulator is assumed to be able to set a linear access charge and a transfer payment to ensure incentive compatibility and participation by the regulated firm. The regulator *cannot*, however, devise a penalty scheme to avoid non-price discrimination.[5] This is consistent with regulatory practice in, for instance, the communications industry where regulators often are restricted to only *instruct* the regulated firm to cease such activities (without the use of penalties).

The rest of the paper is organised as follows. In section 2 the basic model is presented and analysed, in section 3 I investigate the optimal regulation of access charges both when the vertically integrated firm can and cannot use non-price discrimination. In section 4 make some concluding remarks.

2 A model of vertically related markets

There are two firms. Firm v is a vertically integrated firm (VIF), that supplies an essential input for the production of the final product and competes in the final product market. Firm i is an (independent) producer of a final product. The production technology is of a fixed-coefficient type, with each unit of output requiring one unit of input. When determining the access charge, the regulator must take into account that the regulated firm may take some unverifiable actions which affect the

[4] Throughout the paper I assume that the regulator cannot regulate the downstream sector due to reasons external to the model presented below. This is also the starting point of Vickers (1995). A general model of optimal regulation should be able to explain the deregulation of the downstream industry following as the optimal outcome of a complete regulatory setup.

[5] The regulator can, in the absence of uncertainty, device a penalty scheme that makes non-price discrimination prohibitively costly. Specifically, when outputs and prices are different from the no foreclosure case, the regulator penalises the regulated firm sufficiently hard to deter such behaviour.

costs of its downstream rival. It is assumed that the regulator has only imperfect knowledge about the cost of producing the essential input, and therefore utilises incentive contracts to induce truthful revelation.[6]

The demand side

In the downstream market firms are facing the inverse linear demand function, $P(Q) = a - Q$, where $Q = q^v + q^i$ is total production downstream. Net consumers' surplus is in this case given by:

$$CS(Q) = \frac{1}{2}Q^2 \tag{1}$$

Firms and costs

The VIF earns profit in two different markets - the upstream and downstream market. This implies that foreclosing rival firms downstream entails an opportunity cost - the reduction in profits in the upstream activity resulting from a lower overall production level downstream. In addition, foreclosure entails a monetary cost. Activities designed to foreclose rival firms are normally not consistent with competition laws. Consequently, firms that undertake such activities must conceal their actions, and it is realistic to assume that this is costly. Foreclosure is socially wasteful both since total downstream production is reduced and since it involves a monetary cost of the unproductive activity.[7]

The profit function of the independent downstream firm i is given by:

$$\Pi^i = \left(P(Q) - r - \beta^i - w\right) q^i \tag{2}$$

where β^i is the efficiency level, and q^i is the production level of firm i. Let r denote the degree of foreclosure in the access terms for the competitors (unverifiable by the

[6] There is a continuing debate in the industry about the desirability of cost-based access charges. The main reason for assuming imperfect knowledge about the upstream cost only, and not other aspects of the problem, is to focus on the extent to which access charges should be distorted away from marginal costs when these costs are not known by the regulator.

[7] An alternative justification for $C(r)$ could be that a more pronounced level of foreclosure makes it more likely that the competition authorities reveals the unwanted practice, which may lead to a fine being imposed on the firm practicing foreclosure. An extension to the model could incorporate a monetary penalty if foreclosure is detected as an additional regulatory instrument.

regulator). A high level of r is interpreted as a low level of access quality offered to the rival firm, which reduces the willingness to pay for the product sold to end-users. The regulated variable w is the price all downstream firms pay per unit of the inputs purchased from the upstream firm.[8]

The profit function of the VIF is given by:

$$\Pi^v = \left(P(Q) - \beta^d - w\right) q^v + (w - \beta^u) Q - C(r) + t - F \tag{3}$$

where β^d and β^u are the downstream and upstream efficiency levels, q^v is the downstream production of the VIF, Q is the total production downstream, t is the transfer from the regulator, and F is a fixed cost related to upstream production. There are no capacity constraints upstream, and upstream inputs are available to any firm willing to pay the prevailing price.[9] The cost of foreclosure, $C(r)$, is increasing and strictly convex ($C_r > 0$, $C_{rr} > 0$), and is assumed to have the following quadratic form: $C(r) = \varphi r^2/2$. In the case where the integrated firm cannot foreclose its rival, the parameter r is normalised to zero, with $C(0) = 0$.

Welfare and the regulator

The regulator is assumed to maximise a utilitarian welfare function, where transfers awarded to the regulated firm are socially costly due to distortions imposed on other sectors of the economy to raise the revenue. The welfare function is given by:

$$W = CS + \Pi^v + \Pi^i - (1 + \lambda) t \tag{4}$$

[8] All downstream firms obtain access at the same price, including the downstream subsidiary of the upstream firm. For the vertically integrated firm the access charge is, however, simply an internal transfer.

[9] With no capacity constraints upstream, one may argue that price competition is more likely than quantity competition. However, one *ad hoc* justification of the use of quantity competition, may be that each downstream firm must decide on a capacity level prior to entering into the downstream market (e.g., firms must lease lines from the local access provider and these lines are of a fixed capacity). This would imply that each firm has limited capacity in the last stage of the game. In such a situation, and under certain conditions about the capacity levels and the rationing rule, Kreps and Scheinkman (1983) show that the unique outcome of a price competition game with capacity constraints is the Cournot outcome.

where $(1+\lambda)$ is the social cost of transfers to the regulated firm, with $\lambda > 0$. The welfare function is assumed to be concave in w.[10] The basic model is extended to allow for informational asymmetry to examine how imperfect knowledge of the network production costs may affect the determination of access charges. The regulatory agency is assumed to have only imperfect knowledge of the costs upstream. The distribution, $G(\beta^u)$ with the strictly positive density function $g(\beta^u) > 0$, and the support of upstream costs, $\beta^u \in \left[\underline{\beta}, \overline{\beta}\right]$, with $\underline{\beta} \geq 0$ are assumed to be common knowledge. The upstream and downstream costs of the VIF are assumed to be independently distributed, which implies that observation of the downstream costs yields no information about upstream efficiency to the regulator.

Timing of the game

The stages of the game are as follows: At *Stage 1,* the regulator offers a contract of the form $M = \left\{w\left(\widehat{\beta}^u\right), t\left(\widehat{\beta}^u\right)\right\}$ to the regulated firm. At *Stage 2*, the regulated firm reports a type $\widehat{\beta}^u$ to the regulator, and the contract is executed. The regulator assigns the firm a transfer, t, and an access charge, w. At *Stage 3*, the regulated firm decides on the quality of access terms to downstream rivals (the level of foreclosure), r. At *Stage 4*, firms compete á la Cournot in the downstream market.

2.1 Solving the model

Define q^{*v} and q^{*i} as the Cournot equilibrium quantities for the vertically integrated firm and the rival, and let $Q^* = q^{*v} + q^{*i}$ be the total output downstream in equilibrium (see appendix 1 for details). Using the equilibrium quantities, we can express the stage 4 equilibrium profit for firm v as:

$$\Pi^{*v} = \left(q^{*v}\right)^2 + \left(w - \beta^u\right) q^{*i} - \frac{\varphi}{2} r^2 + t - F \tag{5}$$

and for firm i as:

$$\Pi^{*i} = \left(q^{*i}\right)^2 \tag{6}$$

[10] Sufficient conditions to ensure concavity of the welfare function with respect to the access charge are: $\lambda \geq 0$ and $\varphi > 2/3$. The latter assumption also ensures that the single-crossing condition is of constant sign.

Foreclosure benefits the regulated firm through two effects: First, foreclosing the downstream rival reduces its equilibrium output and increases the vertically integrated firm's equilibrium output since quantities are strategic substitutes. Secondly, foreclosure increases the price on the inframarginal units of firm v's output downstream. These benefits are traded off against the opportunity cost of foreclosure, which is due to the contractive effect on upstream profit resulting from lower quantity sold to its rivals and the monetary cost of foreclosure.

When the VIF can foreclose rival firms by degrading the quality of inputs sold to its rivals, r is chosen to maximise Π^v, subject to $q^v = q^{*v}$ and $q^i = q^{*i}$. The profit maximising level of quality degradation r^*, is governed by the following relationship:

$$[(w - \beta^u) + P_Q q^{*v}] \frac{\partial q^{*i}}{\partial r} - C_r = 0 \tag{7}$$

The VIF essentially provides two products; *access* and the *final product.* When the rival firm produces the final product more efficiently, it may better for the VIF to concentrate on the provision of access and leave as much as possible of the production of the final product to the rival. These effects can be identified through a closer examination of VIF's foreclosure incentives.

Observing eqn. (7) we note that if $[(w - \beta^u) + P_Q q^{*v}] > 0$, or equivalently if net marginal profit of an increase in the rival's quantity is positive, then firm v chooses minimum foreclosure; $r^* = 0$. In line with the reasoning of Economides (1998b), we observe that $[(w - \beta^u) + P_Q q^{*v}] > 0$ can only be positive *and* consistent with the existence of profit-maximising downstream rivals if the downstream subsidiary of the VIF is sufficiently inefficient.[11]

Lemma 1 *If $\beta^d > P - w > \beta^i + r$, then $[(w - \beta^u) + P_Q q^{*v}] > 0$.*

This implies that the VIF may wish to shift downstream market shares in favour

[11] Assume $[(w - \beta^u) + P_Q q^{*v}] > 0$. The first-order condition for the profit-maximising quantity choice for the vertically integrated firm is given by: (*) $[P_Q q^{*v} + (w - \beta^u)] + P - \beta^d - w = 0$. Then, the condition $[P_Q q^{*v} + (w - \beta^u)] > 0$ implies $P - w < \beta^d$. The first-order condition for the rival firm is given by: (**) $P_Q q^{*i} + P - \beta^i - w - r = 0$. We observe that if $\beta^i = \beta^d$, condition (**) cannot be satisfied if $r \geq 0$. However, condition (**) can be satisfied if $\beta^d > P - w > \beta^i + r$; i.e., if β^d is sufficiently greater than β^i.

of its own rival if its own downstream subsidiary is sufficiently inefficient, and the VIF effectively outsources (part of) the production of the final product to its rival.

Eqn. (7) can, by using the linear demand function and quadratic cost function, be rewritten as:[12]

$$r^* = \frac{2}{9\varphi - 2}\left(a + \beta^i - 2\beta^d - 2w + \beta^u\right) \tag{8}$$

The profit maximising level of foreclosure has the following properties (see appendix 1 for details): The degree of foreclosure is reduced when the downstream inefficiency of the vertically integrated firm increases; $dr^*/d\beta^d < 0$. The intuition is that higher downstream costs makes it relatively more profitable to offer access downstream (which corresponds to a lower r), rather than to compete in services downstream. A low level of foreclosure will induce the rival to produce a larger part of total output. Furthermore, the degree of foreclosure is increasing in upstream marginal cost. Higher upstream costs makes it less profitable to offer access, and the VIF chooses to compete downstream (corresponds to a higher r) rather than to offer access. The fact that $dr^*/dw < 0$ is a result of r and w being substitute foreclosure activities.[13] A firm selling essential inputs to independent downstream firms, can improve its own downstream subsidiary's position by either increasing the access charge or by reducing the quality of access.[14]

3 Optimal regulation

The focus in the present paper is on regulation of access charges when non-price foreclosure is an option for the regulated firm, and the majority of the analysis

[12] The second-order condition for r^* to be a maximum is $\varphi > 2/9$, which is assumed to be satisfied throughout the paper. If, on the other hand, the second-order condition is not satisfied, the vertically integrated firm will choose a level of r which completely forecloses its rival. Such a convexity arises in, e.g., Mandy (2000).

[13] The latter property has been noted by, e.g., Sibley and Weisman (1998).

[14] This can also be related to the multi-task literature (Holmström and Milgrom, 1991). If the regulated firm is not given enough margin along the regulated dimension, $w - \beta^u$, this may have a negative effect on the unregulated (unobservable) dimension, r. A small margin in the regulated dimension effectively means that the regulated firm is given strong incentives to foreclose.

will focus on the full information case as this case captures many of the interesting implications for regulation of the incentives to foreclose rival firms. The absence of non-price discrimination can be taken to mean that regulators are able to write complete contracts related to the access terms offered to other firms.[15] This can be considered as a benchmark case to investigate the effects of foreclosure on the level of optimal access charges. I will investigate both the unregulated scenario and the case of full information before I procede with the derivation of the socially optimal access charge when the VIF is privately informed about the cost of providing access.[16]

3.1 Unregulated access charge

In an unregulated environment, the VIF can choose to foreclose rival firms using either the access price or through non-price discrimination. Since non-price discrimination is costly for the integrated firm, a preferable (i.e., less costly) method of foreclosure is to set a high access charge. Using the access charge to disadvantage the rival firm has the same qualitative effect as non-price foreclosure, but generates access revenue to the VIF.[17] The unregulated firm maximises profit, $\Pi^v = (q^{*v})^2 + (w - \beta^u) q^{*i} - F$ with respect to w, subject to $q^{*v} \geq 0$ and $q^{*i} \geq 0$.

The solution to the problem is defined as w^{ur}, and is determined by:

$$w^{ur} = \frac{5a - 4\beta^i - \beta^d + 5\beta^u}{10} \tag{9}$$

If $\beta^i = \beta^d = c$, we have $w^{ur} = (a - c + \beta^u)/2$. This implies that $q^{*i} = 0$; the VIF will be a monopolist in both markets, since there are no cost efficiency gains from outsourcing production. If firms are not symmetric, the rival firm will be active in the downstream market provided that it is more efficient than the downstream subsidiary of the VIF.

[15] Alternatively, this case can be interpreted as a situation where the regulator can utilise a wider variety of regulatory instruments (such as monetary penalties).

[16] Although the full information solution is considered as a benchmark case, it is not the first-best solution since the downstream market is unregulated and the number of firms is assumed to be exogenously given.

[17] This is noted by, e.g., Beard, Kaserman and Mayo (2001).

3.2 Full information

The regulator maximises the following problem (substituting for transfer) - [RP 1]:

$$\max_{w} W = \frac{1}{2}Q^2 + (1+\lambda)\left[(q^v)^2 + (w-\beta^u)\, q^i - \frac{\varphi}{2}r^2\right] + \left(q^i\right)^2 - (1+\lambda)\, F - \lambda\Pi^v \tag{10}$$

subject to: *i)* $\Pi^v(\beta^u) \geq 0$ (the participation constraint), *ii)* $r^* = \arg\max_{r} \Pi^v(q^{*v}, q^{*i})$ and *iii)* $q^v = q^{*v} \geq 0$, $q^i = q^{*i} \geq 0$. Since rents to the regulated firm are costly, the regulator will determine transfers such that $\Pi^v(\beta^u) = 0$.

The main trade-off involved in determining the optimal access charge is between minimising the efficiency loss due to market power in the downstream market and minimising the efficiency loss of the transfers. It is assumed that the firms competing downstream possess market power, which implies that there is an inefficiency in this market. This inefficiency will be further exacerbated if the input price is higher than the marginal cost of providing access (i.e., the vertical externality problem). Subsidising the rival's cost (by subsidising access) is one way to correct for this inefficiency. However, there is a second distortion since transfers to the regulated firm must be financed by distortionary taxes. Which of these distortions is the more pronounced will determine the appropriate policy on access pricing. When the latter effect is more important, access should not be subsidised. Whether the optimal access charge is higher or lower than the marginal cost of providing access will depend on which distortion is the more costly at the margin - the cost of public funds, or the deadweight-loss downstream.[18]

3.2.1 Access charge regulation (no foreclosure)

The full information access charge when the VIF cannot use non-price discrimination is denoted w^f_{nr}, and solves [RP 1] (see appendix 2). The optimal access policy calls for an access surplus, except for the case where the downstream subsidiary is highly

[18] The relative efficiency of the downstream firms will also be of importance, as this affects how the downstream inefficiency can be mitigated by transferring production between firms.

inefficient. When the downstream subsidiary is highly inefficient it is better to subsidise the rival to distort market shares to the integrated firm's disadvantage.

Proposition 1 *For symmetric downstream firms and with* $\beta^d = \beta^i = 0$, $w^f_{nr} > \beta^u$ *when* $\lambda > 0.2$. *For shadow cost of public funds below this level, the optimal access charge is always less than* β^u.

It is reasonable that the degree to which there is an access deficit ($w^f_{nr} < \beta^u$) is smaller the higher is the social cost of public funds. When λ becomes large, the cost of transferring a lump-sum payment to the regulated firm imposes a more significant efficiency loss elsewhere in the economy. In this case, optimal policy on access charges shifts from subsidising the rival firm and using compensating lump-sum transfers, to allowing the regulated firm to earn a positive margin on access provision.[19]

The access charge should be set to reflect cost asymmetries between the vertically integrated firm and the independent rival. The optimal access charge is used to ensure that market shares are distorted in favour of the more efficient firm (in the end-user production), with the access charge being (unambiguously) decreasing in β^d and increasing in β^i (see appendix 2). This implies that a level playing field as often advocated by regulators is in general not the socially optimal regulatory regime.[20] A similar result is obtained by Lewis and Sappington (1999).

3.2.2 Access charge regulation (foreclosure)

The constrained optimal access charge, w^f_r, is the solution to the regulator's maximisation problem [RP 1] (see appendix 2). Now, the optimal access charge will

[19] In the presence of fixed costs upstream and prohibition against the use of lump-sum transfers, the optimality of an access subsidy can be questioned. It is then reasonable that the optimal access charge needs to be distorted in excess of marginal cost for Ramsey-reasons to ensure fixed cost recovery.

[20] There is, however, a caveat related to the shadow cost pf public funds. When λ becomes sufficiently large ($\lambda > 5/4$), efficiency in production becomes less important whereas the cost of transfers is the dominating concern since the regulated firm will transfer funds *to* the regulator. The regulator will prefer a high level of profit for the regulated firm which can be taxed away through the regulatory mechanism.

depend not only on relative efficiencies and the social cost of public funds, but also on the convexity of the foreclosure cost function $C(r)$:[21]

Proposition 2 *Assume that $\beta^i = \beta^d = 0$. When the integrated firm can use non-price discrimination, we find that:*

i. $w_r^f > w_{nr}^f$ for all permissible parameter values.

ii. $w_r^f > \beta^u$ for any level of the shadow cost of public funds if $\widetilde{\varphi} > \varphi > 2/3$.

iii. $w_r^f \leq \beta^u$ if λ is sufficiently low and $\overline{\varphi} \geq \varphi \geq \widetilde{\varphi}$.

iv. The optimal access charge is higher when the foreclosure cost is less convex (i.e., the smaller is φ).

Proof. Assume $\beta^i = \beta^d = 0$. Part i): Straightforward but tedious algebraic manipulations, and hence omitted. Part ii) and iii): Define $m \equiv w_r^f - \beta^u$. Then, $m > 0$ iff $(*)$ $(38 - 9\varphi)\varphi + \lambda(4 + (45\varphi - 28)\varphi) - 16 > 0$. A sufficient condition for the second-order condition with respect to w to be satisfied is $\varphi > 2/3$, in which case $(*)$ is satisfied for any $\lambda \geq 0$ if $\widetilde{\varphi} > \varphi > 2/3$, where $\widetilde{\varphi} \equiv \left(19 + \sqrt{217}\right)/9$. If $\overline{\varphi} \geq \varphi \geq \widetilde{\varphi}$, where $\overline{\varphi} \equiv \left(12 + 2\sqrt{73} + \sqrt{346 + 30\sqrt{73}}\right)/9$ defines φ such that $\Pi^{*v} = 0$. Then, $m \leq 0$ for $\lambda = 0$ and, by continuity, for sufficiently small λ (since $\partial m/\partial\lambda > 0$ when $\varphi > 2/3$). Part iv): $\partial m/\partial\varphi < 0$ when $\varphi > 2/3$. ■

From eqn. (8) we have seen that the degree to which the vertically integrated firm chooses to foreclose its rival depends (in part) on the level of the access charge. The higher is the access charge, the lower is the level of foreclosure. If the regulator finds it socially optimal to restrict the activites of independent firms, it is preferable to use the access charge to achieve this. Since there are social costs associated with non-price foreclosure, the optimal access charge should take into account the opportunity to foreclose rivals. Intuitively, this implies setting the access charge higher than is the case when foreclosure is not an option.[22] A high access charge mitigates the

[21] To focus on the core issue of foreclosure, the downstream marginal costs are normalised to zero, but the effect of changes in the downstream marginal costs will be examined briefly below.

[22] To eliminate the foreclosure incentives altogether, the regulator could imitate the unregulated solution as determined by eqn. (9). This results in a (monopoly) deadweight loss in the downstream market.

incentive to foreclose the independent firm, but results in a deadweight loss in the downstream market. Lowering the access charge to correct for the distortion in the downstream market, results in an increased incentive to foreclose.

The second and third part of Proposition 2 relates to the cost of access subsidies. The regulator ideally wishes to subsidise access to correct for the imperfection in the downstream market, but the costs associated with such subsidies restricts the desirability of such a policy. If these costs are neglible, access subsidies may be warranted. By subsidising access the regulated firm is disadvantaged in the downstream market and will use non-price foreclosure to counter this effect. The third part of Proposition 2 also indicates that access may be subsidies even with the possibility of non-price foreclosure when the cost of foreclosure is sufficiently high, since the extent of such behaviour will be negligible.

Part four of Proposition 2 tells us that the socially optimal access charge should somehow reflect the fact that the cost associated with foreclosure restricts the profitability of such activities. When foreclosure is costly, the level of foreclosure is less responsive to changes in the access charge (i.e., $\partial r^*/\partial w$ is less negative when φ is large). If a regulator wants to mitigate the foreclosure problem, this implies that the access charge must be higher than the case when foreclosure is cheap (i.e., when φ is lower).

The desirability for the regulator to distort the access charge to achieve efficiency in production will in the foreclosure case depend not only on the shadow cost of public funds, but also on the cost of foreclosure. For the access charge to distort market shares in favour of the more efficient producer, the access charge must be decreasing in the downstream subsidiary's marginal cost and increasing in the rival's marginal cost:[23]

Proposition 3 *Assume $\lambda < 5/4$. When the vertically integrated firm can exercise non-price discrimination, we observe the following:*

[23] To limit the cases that needs to be considered and to focus on the role that the foreclosure costs play, I will restrict my attention to the cases where $\lambda < 5/4$. When $\lambda \geq 5/4$, a similar situation to the no-foreclosure case arises. The regulator may then find it optimal to ensure a large operating profit to the regulated firm that may be taxed away in the full information case.

i. The optimal access charge distorts downstream market shares in favour of the more efficient firm only when the costs of foreclosure is sufficiently high ($\varphi > (46 - 8\lambda) / (45 - 36\lambda)$).

ii. For low convexity of foreclosure costs ($2/3 < \varphi < 1$), the access charge is no longer used to ensure efficient production in the downstream market.

Proof. The comparative static results for the optimal access charge when foreclosure is possible are given by: $\partial w_r^f / \partial \beta^u > 0$, $\partial w_r^f / \partial a > 0$, and $\partial w_r^f / \partial \beta^d \gtrless 0$, $\partial w_r^f / \partial \beta^i \gtrless 0$. If $\beta^d = \beta^i = c$, then $\partial w_r^f / \partial c < 0$. Let $\varphi > 2/3$ and $\lambda \in [0, 5/4)$. Proof of part i): Define $\kappa_d \equiv \varphi(\lambda)$ to be the convexity level that defines $\partial w_r^f / \partial \beta^d = 0$. Then, $\kappa_d' > 0$ for all λ, with $\lim\limits_{\lambda \to \infty} \kappa_d = 2$. A sufficient condition to ensure $\partial w_r^f / \partial \beta^d < 0$ for all λ, is $\varphi > 2$, whereas for $\lambda < 5/4$, $\varphi > 1$ is sufficient. Furthermore, $\partial w_r^f / \partial \beta^i > 0$ if the following inequality is satisfied: $(*)$ $(45\varphi - 46) + \lambda (8 - 36\varphi) > 0$. Define $\kappa_i \equiv \varphi(\lambda)$ as the convexity such that $\partial w_r^f / \partial \beta^i = 0$. Then, $\kappa_i' > 0$ for all $\lambda \neq 5/4$. If $\lambda < 5/4$, then $(*)$ is satisfied if $\varphi > (46 - 8\lambda) / (45 - 36\lambda)$. If $\lambda \geq 5/4$, then $\partial w_r^f / \partial \beta^i < 0$ for all φ. ■

We know from eqn. (8) that the incentive for foreclosure is negatively related to the downstream cost β^d (and more so the less costly foreclosure is), and that increasing the access charge reduces the incentives to foreclose rivals. When β^d increases, it becomes more likely that the VIF will choose to outsource a larger part of the downstream production to an independent firm. An increase in β^d will then subsequently lower the level of foreclosure *directly* as determined by eqn. (8). In addition, there is an *indirect* effect on the incentives to foreclose rival firms since the access charge is increasing in β^d if $\varphi > 1$. These effects will direct production towards the (relatively) more efficient producer.[24]

The second part of Proposition 3 indicates that the regulator should not (necessarily) use the access charge to distort the market share in favour of the more efficient firm, contrary to the case where non-price discrimination is not possible (cf. Lewis and Sappington, 1999). In some circumstances it may be socially optimal

[24]Note, however, that as λ approaches $5/4$ the convexity of the foreclosure cost function must go towards infinity to ensure that w_r^f is increasing in β^i.

to use the access charge to level the playing field, by using the access charge to offset differences in the downstream marginal costs. This is, in particular, the case if the foreclosure related costs are not too convex. First, if the cost of downstream production increases, total output falls which creates a welfare loss. Second, if the cost of foreclosure is low, the VIF will choose a high level of foreclosure if there is an increase in, e.g., β^d. This results in a lower total output. When foreclosure is sufficiently cheap, the latter contractive effect on total output is more severe than the former (direct) effect. Increasing the access charge would imply a levelling of the playing field. It would also reduce the incentive for non-price foreclosure. Since foreclosure is cheap, the access charge need not be increased substantially to reduce the foreclosure incentives and the output reduction due to an increase in the access charge would be negligible.

3.3 Asymmetric Information

The regulator realises that if the network owner is present downstream, truthful revelation must be based on the joint profit function for the vertically integrated firm, i.e., equation (3). The reason is that the report of efficiency made to the regulator internalises any effects that the report (and resulting infrastructure quality) has on the downstream profits:

Lemma 2 *Local incentive compatibility requires that:*[25]

$$\frac{d\Pi^v}{d\beta^u} = -Q^* + \left[(w - \beta^u) + P_Q q^{*v}\right] \frac{dq^{*i}}{d\beta^u}$$

From lemma 2 we observe that the regulated firm may face countervailing incentives,[26] which come from the process of internalising the effects on downstream profit. Since $dq^{*i}/d\beta^u \geq 0$, a necessary but not sufficient condition for countervailing incentives to be present is $w > \beta^u$.[27] In the present analysis, we assume that

[25]Applying the envelope theorem to (3), given that $\left(q^v, q^i\right)$, and r are chosen optimally (in stages 4 and 3, respectively), we have the following: $\frac{d\Pi^v}{d\beta^u} = \frac{\partial\Pi^v}{\partial\beta^u} + \frac{\partial\Pi^v}{\partial q^i}\frac{dq^{*i}}{d\beta^u}$.

[26]See Lewis and Sappington (1989).

[27]When there are (potentially) countervailing incentives, the standard procedure of assuming

the countervailing effect on incentives never dominate. The sign of the incentive constraint does not change over the relevant interval for β^u, provided that $\varphi > 2/3$ (assumed throughout the paper) and $[(w - \beta^u) + P_Q q^{*v}] < 0$.[28]

The first component of the incentive constraint, $-Q^*$, is also found in, e.g., the Baron and Myerson (1982) model of regulation of a monopolist with unknown costs. Reducing the quantity produced for less efficient types makes it less desirable for efficient types to imitate less efficient types. In the present model, there is in addition an effect on the downstream equilibrium of changing β^u. By the envelope theorem, the change of firm v's downstream quantity from changing β^u does not affect the incentive constraint. The effect of a change in β^u on the competitior's equilibrium quantity affects the price of the final product, and consequently, the incentives for truthful reporting. This must be taken into account when formulating the incentive constraint.

If the sign of the incentive constraint is unambiguously negative for all values of β^u in the support, the firm has only incentives to overstate its upstream costs. The positive element implies that the firm may have incentives to understate its upstream costs for some realisations of the efficiency parameter. The countervailing incentive stems from the fact that a lower level of efficiency (i.e., a higher β^u) effectively increases the equilibrium quantity of firm i. This has some opposing effects: 1) All other things equal, increasing β^u implies that the profitability of selling access is reduced. The information rent must increase to retain incentive compatibility. 2) For a given quantity for firm v, the price on inframarginal units falls due to the increase in firm i's output. To retain incentive compatibility, the information rent must increase. 3) Increased output by firm i has a positive impact on profits, as this increases the revenue the VIF earns on its upstream operations as the rival requires more access capacity.[29] This effect tends towards a lower level of information rents.

that (PC) binds for the least efficient type is no longer valid in the general case, and the participation constraint should be introduced explicitly into the optimisation problem.

[28] If $(w - \beta^u) + P_Q q^{*v} > 0$, we know from lemma 1 that $r^* = 0$, and there will be no foreclosure. Then, a necessary condition for ensuring that $d\Pi^v / d\beta^u < 0 \; \forall \beta^u \in \left[\underline{\beta}, \overline{\beta}\right]$ is $a > w + \beta^d$.

[29] Note that the negative effect on upstream profits from the negative impact that increasing β^u has on q^{*v} disappears by use of the envelope theorem. The only effect to consider is the one related

3.3.1 Socially optimal access charges

The regulator maximises the expected value of the welfare function, with expectations taken over the upstream type of the regulated firm, β^u, subject to participation and incentive constraints.[30] The regulator offers the incentive compatible contract specifying the access charge and transfer, $\left(w\left(\widehat{\beta}^u\right), t\left(\widehat{\beta}^u\right)\right)$, to the upstream firm to induce truthful revelation, using his knowledge of the distribution and support of the unknown parameter, and of the way the game is played in the subsequent stages (see appendix 3 - [RP 2]).

The optimal access charge under asymmetric information, defined as w_r^a if foreclosure is possible and w_{nr}^a if not, is shown to be equal to the optimal access charge under full information plus an incentive correction term (see appendix 3 for details). The magnitude and sign of the incentive correction term will depend on whether the regulated firm can or cannot foreclose its rival. The qualitative insight of the presence of asymmetry of information is, however, unaffected by whether foreclosure is possible. In both cases, there is "no distortion at the top" where the incentive correction term is zero only when $\beta^u = \underline{\beta}$.[31]

Proposition 4 *The socially optimal access charge under asymmetric information is:*

i) Distorted further away from marginal cost than in the full information case; i.e., $w^a - \beta^u > w^f - \beta^u$.

ii) Higher when foreclosure is possible; i.e., $w_r^a > w_{nr}^a$.

Proof: See appendix 3.

to the change in the rival's quantity.

[30] The participation constraint requires that the regulated firm earns non-negative aggregate profits, $\Pi^v \geq 0$, which implies that we need not be concerned with conditions to ensure the profitability of the downstream subsidiary. However, when the participation constraint is applied to aggregate profits this opens up the possibility for cross-subsidisation from the regulated activity (upstream production) to the competitive segment (the downstream industry).

[31] A sufficient condition for the second-order incentive constraint to be satisfied is if the inverse hasard rate is increasing in β; i.e., $\frac{d}{d\beta^u}\frac{G(\beta^u)}{g(\beta^u)} \geq 0$. This assumption is satisfied for a number of distributions.

By setting a high access charge the regulator effectively restricts total output downstream since $\partial Q^*/\partial w < 0$, which is detrimental to welfare. However, this reduces the (socially costly) information rent necessary to induce truthful revelation, since we know from lemma 2 that an access charge in excess of marginal cost introduces an element of countervailing incentives. We observe that $(w^a - \beta^u) > (w^f - \beta^u)$ for a given β^u. When the regulator is imperfectly informed about the regulated firm's cost structure, it is socially optimal to distort the access charge further away from marginal cost of providing access to introduce countervailing incentives. Creating such countervailing incentives can be beneficial from a social welfare point of view as this reduces the information rents.

If the regulated firm can discriminate against rival firms, both the sign and magnitude depends on both the convexity of the cost function and the efficiency of the regulated firm. By increasing the access charge, total downstream output is reduced which induces an efficiency loss. On the other hand, the countervailing incentives becomes more pronounced and truthful revelation is less costly. The main question is then whether the socially optimal access charge is set to favour the more efficient downstream producer. It can be shown that the optimal access charge is decreasing in the marginal cost of the downstream subsidiary (i.e., $\partial w_r^a/\partial \beta^d < 0$) when $\varphi > 4/3$.[32] The optimal access charge is decreasing in β^i whenever $\varphi < 1$, and may be increasing in β^i if $\varphi > 1$ provided that λ is not too large.[33]

3.4 Welfare comparisons

The welfare comparisons between the various regulated cases are quite straightforward. The level of welfare is highest under full information and no foreclosure, and is lowest when there is asymmetric information and foreclosure. The presence of non-price discrimination implies an additional restriction on the welfare maximisation problem. The level of welfare is therefore always higher whenever non-price discrimination is *not* possible. The asymmetry of information imposes yet another

[32]For lower φ, $\partial w_r^a/\partial \beta^d < 0$ if the shadow cost of public funds is low enough.

[33]This is essentially the same as is the case for optimal access charge under full information with foreclosure, w_r^f, as reported in Proposition 3.

constraint on the regulator's problem, which necessarily will have a negative impact on welfare.

If the regulator has full information about upstream costs and the access charge is regulated, welfare is always higher when foreclosure is not possible since the access charge is then a more presice regulatory instrument. When foreclosure is possible, the access charge becomes less precise since it serves an additional purpose (i.e., to mitigate the foreclosure incentives) and the level of welfare is reduced. When there is no access charge regulation, the rival firm is foreclosed completely if both firms' downstream costs are identical. In this situation, the VIF acts as a monopolist both upstream and downstream with the resulting monopoly inefficiency. The regulator could replicate the monopoly outcome if this is socially optimal by implementing the same access charge as the VIF would in the unregulated environment. However, it turns out that when both downstream costs are identical, it is socially optimal to choose less foreclosure than what is observed in the unregulated case. The unregulated outcome is strictly worse in terms of welfare than the regulated outcome.

Contrary to the full information case, welfare may be higher in the unregulated case when the regulator is not perfectly informed about the upstream costs. If non-price discrimination is possible, and assuming that $\beta^d = \beta^i$, welfare is higher without access charge regulation (the unregulated case). When non-price discrimination is not an option, the result is more ambiguous. In the latter case, the magnitude of marginal cost of providing access (β^u) to the market size (given by the parameter a) plays an important role in these welfare comparisons. If the marginal cost of upstream production becomes sufficiently high relative to the size of the market, welfare is highest in the unregulated case. The reason for this is a combination of factors. First of all, the regulator need not award information rents to the vertically integrated firm in the unregulated case. Second, in the unregulated case where the rival is completely foreclosed, the problem of double marginalisation vanishes which has a positive impact on welfare. Finally, as upstream marginal cost increases the total downstream quantity falls faster in the regulated case than in the unregulated case.

The access margin $w - \beta^u$ is increasing in upstream marginal cost if there is asymmetric information, but not in the case with full information. Since total downstream quantity falls when β^u increases, the distortion in the downstream market becomes larger as β^u increases. To mitigate this distortion, the regulator increases the access charge by less than the increase in β^u, which leads the access margin to fall under full information. However, in the presence of asymmetric information, the magnitude of the access margin is important determinant for the level of the information rent, with the information rent being lower the higher is the access margin. The regulator may then choose to accept a larger distortion in the downstream market when β^u increases in order to reduce the costly information rents payable to the regulated firm.

4 Concluding remarks

In a number of countries, including the US and EU, regulatory authorities overseeing the communications industry recommend using a cost based policy with respect to the pricing of access to essential facilities. In both the US 1996 Telecommunications Act and the new regulatory package in the EU, access charges are recommended to be non-discriminatory and cost based and may include a reasonable profit to cover non-traffic sensitive costs. An important reason for pursuing such a policy is that this ensures rival firms access to the essential facility at reasonable terms, with the ultimate goal of increasing the degree of competition to the benefit of consumers. If the vertically integrated firm is allowed to determine access charges without regulatory intervention, it will do so to foreclose rival firms, and, consequently, there is some scope for the regulation of access charges. By focusing too heavily on the costs of providing access in the determination of optimal access charges, the regulators may run the risk of ignoring the possibility that the network owner may choose to discriminate against potential rivals by means of non-price behaviour (such as degrading the quality of access offered to rival firms, which then translates into a lower quality of the rival's final product). Naturally, regulators also put emphasis on quality aspects of access provision, but it is inherently more difficult to regulate quality than price. This implies that even if quality is subject to regulation, it is likely that this regulation is less than perfect and that there will be considerable scope for quality discrimination.

The analysis above suggests that if regulators cannot write complete contracts with respect to the access terms offered to rivals (i.e., the regulators can only control the price a network owner charges, but not the quality of the access), the optimal access charge should be distorted away from marginal costs of providing access to yield a positive profit margin on access. Even if we assume that the regulator can control all aspects of the access terms offered to rival firms (or, alternatively, can use a more comprehensive set of regulatory instruments), the optimal access charge will in general be different from the marginal cost of providing access in situations where there is imperfect competition downstream (and may yield either an access profit or deficit, depending on how socially costly transfers to the regulated firm are).

Previous analysis on access regulation have pointed out that access charges should be set so that production is undertaken as efficient as possible, which involves examining the relative efficiencies of the service providers. The results in the present paper supports such a policy, but it also suggests that the regulation of the access charge should not always be used to award the more efficient downstream firm a larger market share.

Some of the results obtained in the paper may be useful in a policy context, and in particular how vertically integrated firms' opportunities for non-price discrimination should influence the determination of access charges. To focus on the main issue the present analysis is undertaken in a stylised model, which assumes specific functional forms and a particular informational asymmetry. A more general model, both with respect to the informational structure and the demand and cost specifications, would be useful to be able to more forcefully challenge the cost-based access charge regulation.

Finally, the analysis assumes that the regulator does not utilise all available information when designing the regulation mechanism. In particular, examination of practical regulation of the communications industry has led me to exclude the possibility for regulators to set up monetary penalties to avoid non-price discrimination. In a more complete regulatory mechanism, such a penalty should be considered.

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6 Appendicies

Appendix 1

Cournot competition Firm v chooses the level of quantity q^{*v} which maximises Π^v, where Π^v is defined by eqn. (3). Firm i solves a similar maximisation problem, maximising (2) with respect to q^i. The VIF's optimal quantity choice is determined by: $P_Q q^{*v} + \left(P\left(Q^*\right) - \beta^d - \beta^u\right) = 0$. For firm i, the optimal quantity is determined by: $P_Q q^{*i} + \left(P\left(Q^*\right) - \beta^i - w - r\right) = 0$. Solving for equilibrium quantities, we obtain the following: $q^{*v} = \left(a - 2\left(\beta^d + \beta^u\right) + \beta^i + w + r\right)/3$ and $q^{*i} = \left(a - 2\left(\beta^i + w + r\right) + \beta^d + \beta^u\right)/3$. Total downstream quantity is $Q^* = q^{*v} + q^{*i} = \left(2a - \beta^i - \beta^d - \beta^u - w - r\right)/3$.

Quality degradation The profit maximising level of quality degradation r^*, is governed by the following relationship: $\frac{d\Pi^v}{dr} = \frac{\partial \Pi^v}{\partial q^v}\frac{\partial q^{*v}}{\partial r} + \frac{\partial \Pi^v}{\partial q^i}\frac{\partial q^{*i}}{\partial r} + \frac{\partial \Pi^v}{\partial r}$, where $\frac{\partial \Pi^v}{\partial q^v} = 0$ from the envelope theorem, which yields eqn. (7) and can, by using the linear demand function and quadratic cost function, be rewritten as eqn. (8). The profit maximising level of foreclosure has the following properties: $dr^*/d\beta^d = -4/\left(9\varphi - 2\right) < 0$, $dr^*/d\beta^u = 2/\left(9\varphi - 2\right) > 0$, $dr^*/d\beta^i = 2/\left(9\varphi - 2\right) > 0$ and $dr^*/dw = -4/\left(9\varphi - 2\right) < 0$.

Appendix 2

With full information and the absence of non-price discrimination, the socially optimal access charge w^f_{nr} is the solution to [RP 1], and can be written as:

$$w^f_{nr} = \frac{a\left(5\lambda - 1\right) - \beta^d\left(4 + \lambda\right) + \beta^i\left(5 - 4\lambda\right) + \beta^u\left(2 + 5\lambda\right)}{1 + 10\lambda}$$

The second-order condition with respect to w is satisfied in this case since $\lambda > 0$. The comparative statics are as follows: $\partial w^f_{nr}/\partial a = \left(5\lambda - 1\right)/\left(1 + 10\lambda\right) > 0$ if $\lambda > 1/5$, $\partial w^f_{nr}/\partial \beta^d = -\left(4 + \lambda\right)/\left(1 + 10\lambda\right) < 0$, $\partial w^f_{nr}/\partial \beta^i = \left(5 - 4\lambda\right)/\left(1 + 10\lambda\right) > 0$ if $\lambda < 5/4$, and $\partial w^f_{nr}/\partial \beta^u = \left(2 + 5\lambda\right)/\left(1 + 10\lambda\right) > 0$.

When non-price discrimination is an option for the vertically integrated firm, the constrained optimal access charge, w^f_r, is the solution to the regulator's maximisation problem [RP 1], and is given by:

$$\begin{aligned} w^f_r &= \frac{1}{N}\left[a\left(\lambda\left(45\varphi^2 - 28\varphi + 4\right) - 9\varphi^2 + 38\varphi - 16\right)\right. \\ &\quad + \beta^d\left(16 + 8\varphi - 36\varphi^2 + \lambda\left(20\varphi - 9\varphi^2 - 4\right)\right) + \beta^i\left(45\varphi^2 - 46\varphi + \lambda\left(8\varphi - 36\varphi^2\right)\right) \\ &\quad \left. + \beta^u\left(\lambda\left(45\varphi^2 - 28\varphi + 4\right) + 18\varphi^2 + 14\varphi - 12\right)\right] \end{aligned}$$

where $N \equiv \left(9\varphi^2 + 52\varphi - 28 + 2\lambda\left(45\varphi^2 - 28\varphi + 4\right)\right)$. A sufficient condition for concavity of W with respect to w is $\varphi > 2/3$.

Appendix 3

The regulator's optimisation problem is given by [RP 2]:

$$\max_{w} \int_{\underline{\beta}}^{\overline{\beta}} \left[CS\left(w, \beta^u\right) + (1+\lambda) \left[\left(q^v\right)^2 + \left(w - \beta^u\right) q^i - \frac{\varphi}{2} r^2 \right] + \left(q^i\right)^2 \right. \tag{11}$$
$$\left. - (1+\lambda) F - \lambda \Pi^v \right] dG\left(\beta^u\right)$$

subject to 1) $\frac{d\Pi^v}{d\beta^u} = -Q^* + \left[\left(w - \beta^u\right) + P_Q q^{*v}\right] \frac{dq^{*i}}{d\beta^u}$ [IC], 2) $\Pi^v\left(\beta^u\right) \geq 0$ [PC], 3) $dw/d\beta^u \geq 0$ [SIC], 4) $r^* = \arg\max_{r} \Pi^v\left(q^{*v}, q^{*i}\right)$ [S.3], and 5) $q^v = q^{*v} \geq 0$, $q^i = q^{*i} \geq 0$ [S.4]. Constraint S.3 is the profit-maximising level of foreclosure, and S.4 is the Cournot-equilibrium. The participation constraint, [PC], must be satisfied to induce voluntary participation. Constraint SIC, is the second-order incentive constraint, which is checked ex post. It is straightforward to show that since the single-crossing condition $\frac{\partial^2 \Pi^v}{\partial w \partial \beta^u}$ is always positive if $\varphi > 2/3$, then $dw/d\beta^u \geq 0$ is required to ensure implementation of the contract $M = \left\{ w\left(\widehat{\beta}^u\right), t\left(\widehat{\beta}^u\right) \right\}$ (see, e.g., Guesnerie and Laffont, 1984). Maximising expression (11) with respect to w, subject to the constraints defines the optimal access charge under asymmetric information, w^a: $\frac{\partial W}{\partial w} + \lambda \frac{G(\beta^u)}{g(\beta^u)} \frac{\partial^2 \Pi^v}{\partial \beta^u \partial w} = 0$, where W refers to the welfare function under full information. $\frac{\partial^2 \Pi^v}{\partial w \partial \beta^u} = \left((3\varphi - 2)(15\varphi - 2) / (9\varphi - 2)^2 \right)$ in the foreclosure case, and $\frac{\partial^2 \Pi^v}{\partial w \partial \beta^u} = 5/9$ in the no-foreclosure case. Consequently, $w^a > w^f$ since $\frac{\partial^2 \Pi^v}{\partial w \partial \beta^u} > 0$, and $w^a_r > w^a_{nr}$ since W is concave in the access charge and $\frac{\partial^2 \Pi^v}{\partial w^a_r \partial \beta^u} < \frac{\partial^2 \Pi^v}{\partial w^a_{nr} \partial \beta^u}$.