

Matsushima, Noriaki; Mizuno, Keizo

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# Competition for Access Provision: Infrastructure Upgrades with Spillovers

Noriaki Matsushima

Institute of Social and Economic Research, Osaka University

Keizo Mizuno\*

School of Business Administration, Kwansei Gakuin University

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## Abstract

We examine a game of competition with access provision in which service quality is endogenously determined through infrastructure upgrades with spillovers. There are two types of equilibria in the free competition regime. In particular, voluntary access provision with an access charge higher than access cost occurs in equilibrium, irrespective of the degree of spillover and the investment cost. However, foreclosure also occurs in equilibrium when the degree of spillover is small and the investment cost is low. We also show that, when voluntary access provision occurs in equilibrium, access regulation is socially desirable only if the degree of spillover is small and the investment cost is high. On the contrary, access regulation is socially desirable in the broader range of investment cost under foreclosure than under voluntary access provision.

**Keywords:** access provision, infrastructure upgrades, foreclosure.

**JEL classification:** L43, L51, L96.

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\*Corresponding author: Keizo Mizuno, School of Business Administration, Kwansei Gakuin University, 1-1-155 Uegahara, Nishinomiya, Hyogo 662-8501, Japan. Phone: +81-798-54-6181. E-mail: kmizuno@kwansei.ac.jp

# 1 Introduction

Competition in the industries with two-tier structures are abound in real business world. A typical example is found in telecommunications. In broadband markets, facility-based firms, such as regional telephone companies or cable TV companies, have their own infrastructure to provide Internet services to customers, while service-based firms, such as independent internet service providers, need to borrow an infrastructure to offer the services to their customers. In the retail market (i.e., the Internet market), there exists competition that includes not only facility-based firms but also service-based firms. In mobile telephone markets, mobile virtual network operators (MVNO, service-based firms) need to purchase wholesale mobile services from mobile network operators (MNO, facility-based firms) to offer mobile services to their end-users. All the firms, including MVNOs and MNOs, compete each other in the retail market.

The licensing of intellectual property gives another example of competition with two-tier structures. In the licensing markets, firms that own their IP protected technologies can be considered as vertically integrated firms (facility-based firms). They decide whether to license their technologies to potential rival firms and if they license their technologies, they compete with potential rivals (service-based firms) in the product markets.

There are some studies that examine two-tier competition with several vertically integrated firms (facility-based firms) and unintegrated downstream firms (service-based firms). Ordover and Shaffer (2007) address the question of when access to inputs provided by vertically integrated firms are granted to unintegrated downstream firms. They find that unintegrated firms are likely to obtain access when the inputs are not horizontally product-differentiated (i.e., homogeneous). Höffler and Schmidt (2008) asks if granting access to unintegrated downstream firms always enhances social welfare or not. They find that if final products supplied in a downstream market are horizontally product-differentiated, resale (i.e., granting access to unintegrated downstream firms) can be harmful to consumers. Brito and Pereira (2009) (2010) examine endogenous determi-

nation of horizontal product differentiation and show the possibility of high retail prices and the realization of asymmetric product differentiation in the sense that both an entrant and an access provider prefer a closer substitute of products between them than the substitute of products between the entrant and the other vertically integrated firm. Bourreau et al (2011) find that competition between vertically integrated firms can induce the input to be priced at its marginal cost.

This paper provides different characteristics of competition with two-tier structures. Our paper sheds light on three aspects. First, in our model, vertically integrated firms or facility-based firms have an opportunity to invest for the upgrades of inputs, called "infrastructure upgrades". Second, through the infrastructure upgrades, the quality of services supplied downstream is endogenously determined, which means that the relative magnitude of vertical product differentiation among services provided by all firms is endogenously determined. Third, we introduce spillovers generated from infrastructure upgrades, which benefits downstream firms or service-based firms. In sum, we examine a game of competition with access provision in which service quality is endogenously determined through infrastructure upgrades with spillovers.

Featuring these three aspects, the analysis of this paper firstly shows that there are two types of equilibria in the free competition regime; the asymmetric access provision equilibrium and the foreclosure equilibrium. In the asymmetric access provision equilibrium, competition between facility-based firms generates voluntary access provision with the access price that is higher than access cost, irrespective of the degree of spillover and the investment cost. However, the foreclosure equilibrium can also occur when the degree of spillover is small and the investment cost is low. In the foreclosure equilibrium, each of the facility-based firms has a high incentive to invest for infrastructure upgrades. However, there is a room for the facility-based firms to obtain a higher profit under foreclosure than under the asymmetric access provision equilibrium without a high investment when the degree of spillover is not small.

Since voluntary access provision occurs in equilibrium, one may wonder whether government intervention is necessarily required when there is competition in the wholesale market. Thus, we investigate the effect of government intervention in competition with two-tier structures. As an example of government intervention, we examine *symmetric access regulation*. Symmetric access regulation means that all facility-based firms are obliged to grant access to service-based firms with the access charge set by a regulator if downstream firms require access to their infrastructure (or inputs). We show that, when voluntary access provision occurs in equilibrium, access regulation is socially desirable only if the degree of spillover is small and the investment cost is high. On the contrary, access regulation is socially desirable in the broader range of investment cost under foreclosure than under voluntary access provision, because the negative effect of foreclosure overcomes the positive effect of the improvement of service quality by infrastructure upgrades under foreclosure.

These results are explained by the strategic use of access charge and spillovers from infrastructure upgrades. When the facility-based firms can use access charge as their strategic tool, they can expect access profit by attracting service-based firms with spillovers from infrastructure upgrades. Hence, they have a good incentive to invest in infrastructure. Corresponding with this large investment, the access charge higher than access cost can be set by the facility-based firms. Thus, the facility-based firms face competition for access provision in the sense that they try to attract service-based firms to obtain access profit.

On the other hand, when access charge is set by a regulator, a facility-based firm's incentive to invest in infrastructure is weak, because the regulator would like to set access charge as low as possible to induce severe competition downstream from a welfare viewpoint. In that case, spillovers work negatively to facility-based firms as a "free rider effect". Hence, in the access regulation regime, facility-based firms have low incentive to invest in infrastructure. This small investment for infrastructure upgrades can deteriorate social welfare in the access regulation regime.

The effect of spillovers generated from infrastructure upgrades in broadband markets is examined by Foros (2004) and Kotakorpi (2006).<sup>1</sup> They show that access regulation can be harmful for consumers through small investments, depending on the degree of spillover. Although the logic behind their results is very similar to ours, they do not examine the competitive effect between facility-based firms. Our paper extends their analysis by including competition between facility-based firms, and shows that the free rider effect generated from spillovers are overcome by competition for access provision with large investments and high access charges.

The results derived above are reminiscent of R&D race. In fact, free competition for access provision in our model is similar to preemption game in the R&D race with licensing in the sense that the benefits generated from investment for upgrades in goods are likely to be imitated by other players.<sup>2</sup> Hori and Mizuno (2006) and Vareda and Hoernig (2010) apply R&D race game to investments for infrastructure upgrades in an open access environment and investigate whether preemption effect works in that environment.<sup>3</sup> They show that preemption effect emerges even when access seekers have an opportunity to follow their leaders. As in this paper, access charges set by facility-based firms play a critical role to motivate investments for infrastructure upgrades.

Section 2 presents the framework of the model. Section 3 derives the equilibrium in the free competition regime. Section 4 gives the equilibrium in the access regulation regime and compare it with the equilibrium in the free competition regime from a welfare perspective.

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<sup>1</sup>The effect of spillovers are also examined in R&D literature. See d'Aspremont and Jacquemin (1988) and Suzumura (1992). They focus on the comparison of performance between noncooperative R&D and cooperative R&D.

<sup>2</sup>See Fudenberg and Tirole (1985) for preemption effect in the R&D race. Katz and Shapiro (1987) show that licensing or imitation makes R&D innovation to be minor when compared to the case without licensing or imitation.

<sup>3</sup>See Cambini and Jiang (2009) for a survey regarding access regulation and investment in broadband markets.

## 2 The Model

We examine a simple game of competition with access provision. We call it a *free competition regime*, because there is no government intervention in the game. There are two vertically related sectors in a market: an *upstream* sector and a *downstream* sector. The two sectors are required to supply services to consumers in a market. There are three firms; firm 1, firm 2, and firm  $S$ . Each of firm 1 and firm 2, called *facility-based firms*, has its own infrastructure upstream and a production facility downstream (i.e., they are vertically integrated firms). On the other hand, firm  $S$ , called a *service-based firm*, is a potential entrant that has only a production facility downstream. To serve consumers, firm  $S$  needs to access the infrastructure owned by a facility-based firm  $k$  ( $k = 1$  or  $2$ ) by paying an access charge  $a_k$  set by firm  $k$ .

One unit of input (i.e., the output produced upstream) produces one unit of output downstream. The (constant) marginal access cost that a facility-based firm owes for firm  $S$ 's access is the same as its marginal production cost upstream and, for analytical simplicity, they are assumed to be zero. In addition, we assume that the production cost downstream for each firm is zero.

Each of facility-based firms 1 and 2 has an opportunity for investment to upgrade its own infrastructure. Investment to upgrade infrastructure has a demand-enhancing effect because it improves the quality of services sold in the downstream sector. A typical example would be an investment in broadband technology such as FTTH that upgrades the speed or quality of information searches, which would thereby enhance consumer demand.

Following Foros (2004), we employ a linear inverse demand system with vertically differentiated services by supposing that heterogeneous consumers with unit demand for a service are uniformly distributed.<sup>4</sup> The inverse demand function for service  $j$  ( $j = 1, 2, S$ )

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<sup>4</sup>See Foros (2004) for the derivation of this linear inverse demand system for a broadband Internet market. The formulation is originally based on Katz and Shapiro (1985).

is given by

$$p_j = v_j - Q, \quad (j = 1, 2, S)$$

where  $v_j$  represents the quality of service  $j$  and  $Q \equiv q_1 + q_2 + q_S$ . Here,  $v_j$ s ( $j = 1, 2, S$ ) are given by, respectively,

$$v_1 = \alpha + x_1, \quad v_2 = \alpha + x_2, \quad v_S = \alpha + sx_k$$

where  $\alpha$  is a positive constant that represents consumers' willingness-to-pay for a service supplied using an old infrastructure,  $x_k$  ( $k = 1, 2$ ) is the investment level of firm  $k$ , and  $s$  is the degree of spillover from a facility-based firm  $k$  that firm  $S$  accesses. Note that the quality of services sold in the downstream sector is endogenously determined by facility-based firms' investments for infrastructure upgrades upstream. For analytical simplicity, we assume the same investment technology between firms 1 and 2, which is represented by  $I(x_k) = (\gamma x_k^2)/2$  where  $\gamma (> 0)$  is an investment cost parameter of firms 1 and 2.

The degree of spillover  $s$  reflects the relative inferiority or superiority of firm  $S$ 's retail production technology as compared to that of the facility-based firm that firm  $S$  accesses. In the following analysis, we restrict our attention to the case in which firm  $S$ 's retail production technology is inferior (or at best identical) to that of the facility-based firm;  $s \in [0, 1]$  (as will be shown in the analysis, however, the qualitative results derived for the case in which  $s > 1$  are the same as those for the case in which  $s = 1$ ). This restriction is justified by a facility-based firm's better position to obtain the knowledge of an upgraded infrastructure and swiftly adjust its retail production technology to the infrastructure.

To preserve analytical tractability, we make the following assumptions.

**Assumptions** (i)  $a_k \geq 0$  ( $k = 1, 2$ ), (ii)  $\gamma > 3/2$ .

Assumption (i) is set for practical reasons.<sup>5</sup> In fact, it is rare for access charges to be set below the marginal access cost in the real policy arena. Assumption (ii) guarantees

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<sup>5</sup>This assumption also appears in Foros (2004).

an interior solution for facility-based firms' profit-maximizing investment problems, as ensured in the following analysis.

The timing of the game is as follows. In the first stage, the two facility-based firms, firm 1 and firm 2, simultaneously invest for infrastructure upgrades. In the second stage, observing the levels of investments  $x_1$  and  $x_2$ , firm 1 and firm 2 simultaneously set the access charges  $a_1$  and  $a_2$  independently. In the third stage, firm  $S$  decides whether to enter the market by accessing one of facility-based firms.<sup>6</sup> For analytical simplicity, we assume that firm  $S$ 's entry sunk cost is zero. In the fourth stage, all active firms compete downstream in a Cournot fashion.

### 3 Equilibria in the Free Competition Regime

#### 3.1 Preliminary results: the equilibria in the third and fourth stages

The profit function of a facility-based firm  $k$  that firm  $S$  accesses and that of a facility-based firm  $l$  that firm  $S$  does not access are represented by, respectively,

$$\pi_k = p_k q_k + a_k q_S - I(x_k), \quad \pi_l = p_l q_l - I(x_l), \quad k, l = 1, 2, \text{ and } k \neq l.$$

The profit function of firm  $S$  if it enters the market is represented by

$$\pi_S = (p_S - a_k) q_S,$$

and  $\pi_S = 0$  if firm  $S$  does not enter the market.

When firm  $S$  enters the market in the third stage, a triopoly appears in the fourth stage. Solving the maximization problems of the firms, we have the equilibrium quantities

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<sup>6</sup>We assume that when the access conditions offered by firm 1 and firm 2 are indifferent from firm  $S$ 's point of view, the probability of access to each of facility-based firms is 0.5.

as follows:

$$q_k(a_k; x_k, x_l) = \frac{\alpha + a_k + (3 - s)x_k - x_l}{4}, \quad (1)$$

$$q_l(a_k; x_k, x_l) = \frac{\alpha + a_k - (1 + s)x_k + 3x_l}{4}, \quad (2)$$

$$q_S(a_k; x_k, x_l) = \frac{\alpha - 3a_k - (1 - 3s)x_k - x_l}{4}, \quad (3)$$

$$Q(a_k; x_k, x_l) = \frac{3\alpha - a_k + (1 + s)x_k + x_l}{4}. \quad (4)$$

where  $q_k(\cdot)$  ( $q_l(\cdot)$ ) is the equilibrium quantity of firm  $k$  that firm  $S$  accesses (does not access). Note that if the degree of spillover  $s$  is larger than  $1/3$ , the investment of firm  $k$  increases the quantity of firm  $S$ . From (1) to (4), the equilibrium profits in the subgame of the fourth stage are given by

$$\pi_k(a_k; x_k, x_l) = (q_k(a_k; x_k, x_l))^2 + a_k q_S(a_k; x_k, x_l) - I(x_k), \quad (5)$$

$$\pi_l(a_k; x_k, x_l) = (q_l(a_k; x_k, x_l))^2 - I(x_l), \quad (6)$$

$$\pi_S(a_k; x_k, x_l) = (q_S(a_k; x_k, x_l))^2. \quad (7)$$

If firm  $S$  does not enter the market, a duopoly appears in the fourth stage. The equilibrium quantities supplied by firms 1 and 2 are given by

$$\tilde{q}_1(x_1, x_2) = \frac{\alpha + 2x_1 - x_2}{3}, \quad \tilde{q}_2(x_1, x_2) = \frac{\alpha + 2x_2 - x_1}{3}. \quad (8)$$

From (8), the equilibrium profits in the subgame are given by

$$\tilde{\pi}_1(x_1, x_2) = (\tilde{q}_1(x_1, x_2))^2 - I(x_1), \quad \tilde{\pi}_2(x_1, x_2) = (\tilde{q}_2(x_1, x_2))^2 - I(x_2).$$

In the third stage, firm  $S$  determines whether to enter the market by accessing the infrastructure of firm  $k$  ( $k = 1$  or  $2$ ) with the payment of  $a_k$ . The necessary and sufficient conditions for firm  $S$  to enter the market and to access firm  $k$  are given by  $q_S(a_k; x_k, x_l) \geq 0$

and  $q_S(a_k; x_k, x_l) \geq q_S(a_l; x_k, x_l)$ , which we can rewrite as follows:

$$a_k \leq \overline{a_k} \equiv \frac{1}{3} (\alpha - (1 - 3s) x_k - x_l), \quad (9)$$

$$a_k - s x_k \leq a_l - s x_l. \quad (10)$$

(9) means that the access charge set by firm  $k$  must be small so that firm  $S$  can obtain a positive profit in the market. (10) implies that firm  $k$  needs to offer a more profitable condition to firm  $S$  than firm  $l$  does. Note that the profitability condition for firm  $S$  includes not only the access charge but also the spillover effect generated from infrastructure upgrades.

Firm  $S$  does not enter the market when  $q_S(a_k; x_k, x_l) < 0$ . That is,

$$a_k \leq \overline{a_k} \equiv \frac{1}{3} (\alpha - (1 - 3s) x_k - x_l), \quad k, l = 1, 2, \text{ and } k \neq l.$$

### 3.2 The equilibrium access charges

We examine the second stage in which two facility-based firms, firm 1 and firm 2, set their own access charges  $a_1$  and  $a_2$  independently. The access charge set by each of the two facility-based firms depends not only on the rival's access charge but also on the levels of the investment for infrastructure upgrades  $x_1$  and  $x_2$  determined in the first stage.

The equilibrium access charges in the second stage are characterized as shown in the following lemma.

**Lemma 1** *The equilibrium access charges  $a_1^*$  and  $a_2^*$  in the second stage of the game are characterized as follows:<sup>7</sup>*

$$a_k^* = a_l^* = 0 \text{ if } x_k = x_l,$$

$$a_k^* = s(x_k - x_l) \text{ and } a_l^* = 0 \text{ if } x_k > x_l, \quad k, l = 1, 2, \text{ and } k \neq l.$$

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<sup>7</sup>In the expression of equilibrium here,  $a_k^* = s(x_k - x_l)$  ( $k, l = 1, 2$ , and  $k \neq l$ ) ignores the small reduction of  $\varepsilon$ . More precisely, the equilibrium access charge is written as  $a_k^* = s(x_k - x_l) - \varepsilon$ .

Moreover, when  $s < 7/9$ ,  $\alpha - (7 - 9s)x_1 - x_2 < 0$  and  $\alpha - (7 - 9s)x_2 - x_1 < 0$ , there are also pairs of equilibrium access charges  $(a_1^*, a_2^*)$  where  $a_k^* \geq \overline{a_k} \equiv \frac{1}{3}(\alpha - (1 - 3s)x_k - x_l)$  ( $k, l = 1, 2, k \neq l$ ) in addition to those mentioned above.

**Proof.** See Appendix. ■

The result of Lemma 1 is very intuitive. When the investment levels are the same between firm 1 and firm 2, each of them has an incentive to reduce its access charge to attract firm  $S$ . As a result, access charge is equal to access cost in equilibrium, and each of facility-based firms is accessed by firm  $S$  with probability 0.5. This result is similar to the one in Bertrand price competition with homogeneous goods. When the investment of one firm is larger than the other's, that firm can set access charge to be higher than access cost and is accessed by firm  $S$  with probability 1. Then, the firm with larger investment can obtain a positive access profit.

We should note that when  $s < 7/9$ , there are two kinds of equilibrium access charge if the total investments of two facility-based firms are large (i.e., if  $\alpha - (7 - 9s)x_1 - x_2 < 0$  and  $\alpha - (7 - 9s)x_2 - x_1 < 0$ ). In particular, if a facility-based firm  $j$  sets a high access charge (i.e.,  $a_j^* \geq \overline{a_j}$ ) to foreclose firm  $S$ , the other facility-based firm  $i$  also has an incentive to set a high access charge (i.e.,  $a_i^* \geq \overline{a_i}$ ). These access pricing strategies are reasonable as long as the total investments are large. In fact, this is the case especially when the degree of spillover  $s$  is small. On the contrary, if a facility-based firm sets a low access charge to attract firm  $S$  and obtain access profit, the other facility-based firm also has an incentive to lower its access charge. As a result, competition for access provision occurs even when the total investments are large.

### 3.3 Strategic investments and access provision

In the first stage, firms 1 and 2 invest for infrastructure upgrades. The following proposition states the characterization of the equilibria in the free competition regime.

**Proposition 1** *In the free competition regime, there exist two types of equilibrium; an asymmetric access provision equilibrium (AAPE) and a foreclosure equilibrium (FE) (or a constrained foreclosure equilibrium (CFE)). Each of the equilibria is characterized as follows:*

(i) *In AAPE,  $a_k^{*AAPE} = s (x_k^{*AAPE} - x_l^{*AAPE})$  and  $a_l^{*AAPE} = 0$  ( $k, l = 1, 2$ , and  $k \neq l$ ), and the equilibrium investments are  $x_k^{*AAPE} = \Phi(s, \gamma) / \Theta(s, \gamma)$  and  $x_l^{*AAPE} = \Psi(s, \gamma) / \Theta(s, \gamma)$  where*

$$\begin{aligned}\Theta(s, \gamma) &\equiv (8\gamma - (9 - 4s))(8\gamma - (3 - s)^2) - 3(2s + 1)(1 - s)(3 - s), \\ \Phi(s, \gamma) &\equiv 2(4(3 + 2s)\gamma - (3 - s)(6 - 3s - 4s^2)), \\ \Psi(s, \gamma) &\equiv 2\alpha(3 - s)(4\gamma - (6 - s)).\end{aligned}$$

*Then, firm  $k$  is accessed by firm  $S$  with probability 1. This equilibrium occurs irrespective of the degree of  $s$  and the investment cost.*

(ii) *In FE,  $x_1^{*FE} = x_2^{*FE} = (4\alpha) / (9\gamma - 4)$  and firm  $S$  does not enter the market. This equilibrium occurs only when  $\gamma \leq 4(1 - s)$ .*

(iii) *In CFE,  $x_1^{*CFE} = x_2^{*CFE} = \alpha / (8 - 9s)$  and firm  $S$  does not enter the market. This equilibrium occurs only when  $\gamma > 4(1 - s)$  and  $\Omega(s, \gamma) < 0$  where*

$$\Omega(s, \gamma) \equiv \gamma(7 - 9s)^2 - (8\gamma - (3 - s)^2)(18(1 - s)^2 - \gamma).$$

**Proof.** See Appendix. ■

[Insert Figures 1, 2, and 3]

According to Proposition 1, two types of equilibrium are possible in the free competition regime. The first type of equilibrium is *the asymmetric access provision equilibrium*

(AAPE), and the second type is *the foreclosure equilibrium (FE)* (or *the constrained foreclosure equilibrium (CFE)*).

In the AAPE, one of the facility-based firms is accessed by firm  $S$ , and that firm can achieve the access charge that is higher than access cost. Thus, the firm accessed by firm  $S$  can obtain access profit. The basis for this positive access profit is the fact that the right to determine access charge is delegated to the facility-based firms. Furthermore, because of the opportunity to obtain access profit, each of the facility-based firms has a high incentive to invest for the improvement of service quality or infrastructure upgrades.<sup>8</sup> In particular, the firm that is accessed by firm  $S$  achieves more investment than the other firm does as a result of access provision competition. Thus, there is a quality difference between the two facility-based firms. Figure 1 allows us to ensure this characteristic of the AAPE.

In Figure 1, firm 1's (firm 2's, respectively) reaction function is the solid parts of  $x_1^{*1}(x_2)$  and  $x_1^{*2}(x_2)$  ( $x_2^{*1}(x_1)$  and  $x_2^{*2}(x_1)$ , respectively). As shown in the figure, each firm's reaction function is discontinuous at  $\hat{x}_i$  ( $i = 1, 2$ ). This is because the opportunity for each firm to be accessed by firm  $S$  and the access charge set in the second stage depends on the relative magnitude of investment between firm 1 and firm 2. See firm 1's reaction function, for example. We note that  $x_1^{*1}(x_2)$  stands more left than  $x_1^{*2}(x_2)$ . This implies that firm 1 has more incentive to invest when it is accessed by firm  $S$  than when it is not accessed. This is the same for firm 2. When a facility-based firm can use access charge as its strategic tool, it can expect access profit by attracting a service-based firm that gains benefits of spillovers from infrastructure upgrades. Hence, it has a good incentive to invest in infrastructure. Corresponding with this large investment, the access charge higher than access cost can be set by the facility-based firm. From the result of the large investment with spillovers, we can state that the facility-based firms face competition for access provision in the sense that they try to attract a service-based firm to obtain access

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<sup>8</sup>See Figure 6-1 that appears later.

profit.

Another type of equilibrium is the FE. Figure 2 depicts the foreclosure equilibrium (FE). The foreclosure equilibrium occurs when the investment cost is low and the degree of spillover is small, i.e.,  $\gamma \leq 4(1 - s)$ . When the investment cost is low, each of firm 1 and firm 2 has a high incentive to invest for infrastructure upgrades. Moreover, when the degree of spillover is small, the benefit for firm  $S$  is small. Then, firm  $S$  loses an incentive to enter the market in that case. However, if the degree of spillover is sufficiently small, each of the facility-based firms may not need to highly invest to foreclose firm  $S$ , because a sufficiently small spillover itself creates a large foreclosure effect.<sup>9</sup> Moreover, there is a room for the facility-based firms to obtain a higher profit under foreclosure than under the AAPE with excessive investment even when the degree of spillover is not small. We define this situation as *the constrained foreclosure equilibrium (CFE)*.

Figure 3 describes all the equilibria in the free competition regime in  $(s, \gamma)$  plane. When the degree of spillover  $s$  is large, the AAPE definitely occurs in the free competition regime. In other words, voluntary access provision definitely occurs in the free competition regime. Otherwise, both of the AAPE and the FE (or the CFE) are possible.

## 4 Comparison with the Access Regulation Regime

### 4.1 Access regulation equilibria

In the free competition regime, there is competition for access provision among the facility-based firms. The competition for access provision induces voluntary access provision with a low access charge and a high investment for the improvement of service quality or infrastructure upgrades. Thus, the natural question is: do we need a government intervention when there is competition for access provision in the industries with two-tier structures? To answer this basic question, we prepare a government intervention regime

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<sup>9</sup>See Figure 6-2 regarding this point.

in this subsection. In the next subsection, we compare it with the free competition regime and evaluate the necessity of a government intervention.

The government intervention we examine in this paper is access regulation. The *access regulation regime* is defined as the regime in which a benevolent regulator can determine the access charge instead of a facility-based firm. This regime is prevalent in telecommunications worldwide especially in the Internet or broadband markets. Moreover, in this paper, we assume that the access regulation is *symmetric*, i.e., the regulated access charge is applied to each of two facility-based firm if it is accessed by firm  $S$ .<sup>10</sup>

The equilibria in the third and fourth stages are the same as in the free competition regime. In the second stage, the regulator sets the cost-based access charge, i.e.,  $a^* (= a_1^* = a_2^*) = 0$ , under the assumption that  $a \geq 0$ , as long as  $\alpha$  is sufficiently large.<sup>11</sup> Then, the following proposition characterizes the equilibria in the access regulation regime.

**Proposition 2** *In the access regulation equilibria (ARE),  $a_1^{*ARE} = a_2^{*ARE} = 0$  and  $x_1^{*ARE} = x_2^{*ARE} \in [x^{ARB}, x^{ARA}]$  where*

$$x^{ARB} = \frac{(3-s)\alpha}{8\gamma - (3-s)(2-s)} \text{ and } x^{ARA} = \frac{3\alpha}{8\gamma - 3(2-s)}.$$

*Then, each of facility-based firms are accessed by firm  $S$  with probability 0.5, irrespective of the degree of spillover and the investment cost.*

**Proof.** See Appendix. ■

[Insert Figure 4]

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<sup>10</sup>In reality, asymmetric access regulation, also known as "dominant regulation", has still been prevalent in telecommunications of many countries. However, since the market share of bypass gradually expands as a result of the technology progress or technology convergence, some countries try to adopt symmetric access regulation. For example, Belgium now sets out to adopt symmetric access regulation.

<sup>11</sup>When  $\alpha$  is not sufficiently large but still firms obtain positive profits, there is a possibility that the regulator sets the access charge that is higher than access cost when the degree of spillover is small. See Mizuno and Yoshino (2012) on this point.

Figure 4 shows the access regulation equilibria (ARE). Contrary to Figure 1, we see that each firm's reaction function is continuous but is kinked at  $x_i^{ARA}$  and  $x_i^{ARB}$  ( $i = 1, 2$ ). As stated in Section 3.3, this is because the opportunity for each of facility-based firms to be accessed by firm  $S$  depends on the relative magnitude of investment between firm 1 and firm 2. Interestingly, firm 1's reaction function stands more left when  $x_1 > x_2$  than when  $x_1 < x_2$ . This implies that firm 1 has less incentive to invest when it is accessed by firm  $S$  than when it is not accessed. This is the same for firm 2. When access charge is set to access cost by the regulator, a facility-based firm's incentive to invest in infrastructure is weak, because the regulator sets access charge as low as possible to induce severe competition downstream from a welfare perspective. In that case, spillovers work negatively to facility-based firms as a "free rider effect". Hence, in the access regulation regime, facility-based firms have little incentive to invest in infrastructure. Then, this small investment in infrastructure upgrades may deteriorate social welfare in the access regulation regime.

We also note that there are multiple equilibrium investments in the access regulation regime. It is easy to guess that the equilibrium with the highest investment achieves the highest social welfare.

## 4.2 Welfare comparison

Now we compare the equilibria in the free competition regime and those in the access regulation regime from a welfare perspective. In our model, social welfare,  $SW$ , is defined as the sum of consumer surplus and firms' profits. Specifically, consumer surplus is given by

$$CS = \frac{(Q(a; x_1, x_2))^2}{2},$$

and firm  $k$ 's profit,  $\pi_k$ , is given in section 2.

[Insert Figures 5-1 and 5-2]

Figures 5-1 and 5-2 shows the welfare comparison between the equilibria in the free competition regime and the ARE in the access regulation regime with the setting of  $\alpha = 50$ .<sup>12</sup> In the access competition regime, the ARE with the highest investment are taken to be compared with the equilibria in the free competition regime. Moreover, since the two types of equilibrium ( i.e., the AAPE and the FE (or the CFE)) appear in the free competition regime, we compare each of the equilibria with the ARE separately.

First, we compare the AAPE and the ARE. See Figure 5-1. One critical finding is that social welfare in the AAPE is higher than that in the ARE in the substantial parts of the range of  $(s, \gamma)$ . This is because the facility-based firms have a higher incentive for the improvement of service quality in the AAPE, which in turn induces a larger consumer surplus in the AAPE than in the ARE. However, when the degree of spillover is small and the investment cost is high, the ARE can achieve a higher welfare than the AAPE. Here, we should note that consumer surplus is larger in the AAPE than in the ARE in that situation, because the production expansion effect generated from more investment works in the AAPE. However, firms' total profits are larger in the ARE than in the AAPE. This comes mainly from firm  $S$ 's large profit in the ARE, because the access charge is low in the ARE. Then, since the effect of large total profits overcomes that of small consumer surplus, the ARE achieves larger social welfare than the APPE does.

According to Figure 5-2, when the FE, not the CFE, is realized in the free competition regime, social welfare in the FE is always higher than that in the ARE. There are two factors that explain this phenomenon. First, each of two facility-based firms can achieve higher profits in the free competition regime than in the access regulation regime. This is because the firms can use two strategic tools (i.e., access charge and investment) in the free competition regime, whereas they use only one tool (i.e., investment) in the access regulation regime. Moreover, the firms' higher market power also increases their profits in the FE. Second, two facility-based firms have more incentive to invest for infrastructure

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<sup>12</sup>The qualitative features of the welfare comparison does not change when the value of  $\alpha$  changes.

upgrades in the free competition regime than in the access regulation regime. The second factor alleviates smaller production (i.e., smaller consumer surplus) generated from their market power in the FE.

On the other hand, when the CFE is realized in the free competition regime, the negative effect of foreclosure overcomes the positive effect of the improvement of service quality. In fact, although the investment incentive of the facility-based firms is excessive from its profit-maximizing viewpoint, it is not sufficiently high to induce higher consumer welfare than that in the ARE. Hence, social welfare in the CFE is lower than that in the ARE. In that case, we need access regulation from a welfare perspective.

These characteristics are summarized in the following proposition.

**Proposition 3** *(i) Social welfare in the access regulation equilibrium is higher than that in the asymmetric access provision equilibrium only when the degree of spillover is small and the investment cost is high.*

*(ii) Social welfare in the access regulation equilibrium is lower than that in the foreclosure equilibrium.*

*(iii) When the constrained foreclosure equilibrium is realized, access regulation is desirable from a welfare perspective.*

[Insert Figures 6-1 and 6-2]

Figure 6-1 (6-2, respectively) shows the comparison of the levels of investment between the AAPE (the FE or the CFE, respectively) and the ARE. These figures allow us to ensure the intuitive reasoning of welfare comparison.

## 5 Concluding Remarks

In this paper, competition with two-tier structures have been examined. Specifically, we have examined a game of competition with access provision in which service quality is

endogenously determined through infrastructure upgrades with spillovers.

The analysis of this paper has shown that two types of equilibria are possible in the free competition regime; the asymmetric access provision equilibrium and the foreclosure equilibrium. In the asymmetric access provision equilibrium, competition between facility-based firms induces voluntary access provision with the access price that is higher than access cost, irrespective of the degree of spillover and the investment cost. However, the foreclosure equilibrium can also occur when the degree of spillover is small and the investment cost is low. In the foreclosure equilibrium, each of the facility-based firms has a high incentive to invest for infrastructure upgrades. However, there is a room for the facility-based firms to obtain a higher profit under foreclosure than under the asymmetric access provision equilibrium with excessive investment when the degree of spillover is not small.

We have also investigated the effect of symmetric access regulation. It has been shown that, when voluntary access provision occurs in equilibrium, access regulation is socially desirable only if the degree of spillover is small and the investment cost is high. On the contrary, access regulation is socially desirable in the broader range of investment cost under foreclosure than under voluntary access provision, because the negative effect of foreclosure overcomes the appositive effect of the improvement of service quality.

## Appendix

### The proof of Lemma 1

First, we characterize the access pricing strategy of each of facility-based firms. In the following, we examine firm 1's strategy, for example.

Under a pair of investments,  $(x_1, x_2)$ , set in the first stage, firm 1 decides the optimal access charge,  $a_1^*$ , taking  $a_2$  as given. There are two cases.

(i) When  $a_2 > \bar{a}_2 \equiv (\alpha - (1 - 3s)x_2 - x_1)/3$ , firm  $S$  does not access firm 2's infrastruc-

ture to enter the market.

Then, if firm 1 offers  $a_1 > \bar{a}_1 \equiv (\alpha - (1 - 3s)x_1 - x_2)/3$ , firm  $S$  does not enter the market. Thus, firm 1's profit is  $\tilde{\pi}_1(x_1, x_2)$ . On the contrary, if firm 1 offers  $a_1 \leq \bar{a}_1$ , firm  $S$  enters the market by accessing firm 1's infrastructure, firm 1's profit becomes  $\pi_1(a_1; x_1, x_2)$ . Maximizing  $\pi_1(a_1; x_1, x_2)$  with respect to  $a_1$  gives

$$a_1^M = \frac{1}{11} (3\alpha + (1 + 5s)x_1 - 3x_2). \quad (11)$$

Because  $\pi_1(a_1; x_1, x_2)$  is continuous in  $a_1$ , we have  $\pi_1(\bar{a}_1; x_1, x_2) = \tilde{\pi}_1(x_1, x_2)$ . Moreover, because  $\pi_1(a_1; x_1, x_2)$  is concave in  $a_1$ , we have

$$\pi_1(a_1^M; x_1, x_2) \geq (<) \tilde{\pi}_1(x_1, x_2) \text{ if and only if } a_1^M \leq (>) \bar{a}_1.$$

Furthermore, we have

$$a_1^M \leq (>) \bar{a}_1 \text{ if and only if } \alpha - (7 - 9s)x_1 - x_2 \geq (<) 0.$$

That is, if  $\alpha - (7 - 9s)x_1 - x_2 \geq 0$ ,  $a_1^* = a_1^M$ . Otherwise,  $a_1^* \in [\bar{a}_1, \infty)$ .

(ii) When  $a_2 \leq \bar{a}_2$ , firm  $S$  has an incentive to access firm 2's infrastructure to enter the market. In this case, firm 1's access pricing strategy depends on whether the profit with firm  $S$ 's access is greater than the profit without it. In particular, we have

$$\begin{aligned} a_1^* &= a_2 - s(x_2 - x_1) \text{ if } \pi_1(a_1; x_1, x_2) > \pi_1(a_2; x_1, x_2), \\ a_1^* &\in (a_2 - s(x_2 - x_1), \infty) \text{ if } \pi_1(a_1; x_1, x_2) < \pi_1(a_2; x_1, x_2), \text{ and} \end{aligned}$$

$a_1^*$  remains unchanged if  $\pi_1(a_1; x_1, x_2) = \pi_1(a_2; x_1, x_2)$ . Here, we can ensure that  $\pi_1(a_1; x_1, x_2) > \pi_1(a_2; x_1, x_2)$  as long as  $a_1 < \bar{a}_1$  and  $a_2 < \bar{a}_2$ . The reason is as follows: first of all, we ensure that  $\pi_1(a_1^*; x_1, x_2) > \pi_1(a_2; x_1, x_2)$  at  $a_1^* = a_2 - s(x_2 - x_1)$ . Then, if firm 1 raises

access charge from  $a_1^*$  for a small amount, i.e.,  $a_1^* + \varepsilon$ , its profit becomes  $\pi_1(a_2; x_1, x_2)$ , which is smaller than  $\pi_1(a_1^*; x_1, x_2)$ .<sup>13</sup> Therefore,  $a_1^* = a_2 - s(x_2 - x_1)$  for any  $a_2 \leq \bar{a}_2$ . This means that two facility-based firms face price competition for access provision.

Summarizing the discussions of (i) and (ii), firm 1's access pricing strategy is stated as follows: when  $a_2 > \bar{a}_2$ ,  $a_1^* = a_1^M$  if  $\alpha - (7 - 9s)x_1 - x_2 \geq 0$ . If  $\alpha - (7 - 9s)x_1 - x_2 < 0$ ,  $a_1^* \in [\bar{a}_1, \infty)$ . On the other hand, when  $a_2 \leq \bar{a}_2$ ,  $a_1^* = a_2 - s(x_2 - x_1)$ . Firm 2's access pricing strategy is the same as that of firm 1 by changing the identification number of firm.

Given each firm's access pricing strategy, we can derive Nash equilibria in the second stage. In fact, the equilibria depends on the level of  $s$ . First, we examine the case in which  $s \leq 7/9$ . In this case, there are four cases, depending on the levels of  $x_1$  and  $x_2$ .

*Case1:* the case in which  $\alpha - (7 - 9s)x_1 - x_2 \geq 0$  and  $\alpha - (7 - 9s)x_2 - x_1 \geq 0$ .

In this case, when  $x_1 = x_2$ , the Nash equilibrium access charges are  $\{a_1^*, a_2^*\} = \{0, 0\}$ . When  $x_1 > x_2$ ,  $\{a_1^*, a_2^*\} = \{s(x_1 - x_2), 0\}$ . When  $x_1 < x_2$ ,  $\{a_1^*, a_2^*\} = \{0, s(x_2 - x_1)\}$ .

*Case2:* the case in which  $\alpha - (7 - 9s)x_1 - x_2 < 0$  and  $\alpha - (7 - 9s)x_2 - x_1 < 0$ .

In this case, when  $x_1 = x_2$ , the Nash equilibrium access charges are  $\{a_1^*, a_2^*\} = \{0, 0\}$  or any pair of  $a_1$  and  $a_2$  such that  $a_1 > \bar{a}_1$  and  $a_2 > \bar{a}_2$ . When  $x_1 > x_2$ ,  $\{a_1^*, a_2^*\} = \{s(x_1 - x_2), 0\}$  or any pair of  $a_1$  and  $a_2$  such that  $a_1 > \bar{a}_1$  and  $a_2 > \bar{a}_2$ . When  $x_1 < x_2$ ,  $\{a_1^*, a_2^*\} = \{0, s(x_2 - x_1)\}$  any pair of  $a_1$  and  $a_2$  such that  $a_1 > \bar{a}_1$  and  $a_2 > \bar{a}_2$ .

*Case3:* the case in which  $\alpha - (7 - 9s)x_1 - x_2 \geq 0$  and  $\alpha - (7 - 9s)x_2 - x_1 < 0$ .

Note that only the region where  $x_1 < x_2$  is relevant in this case. Then,  $\{a_1^*, a_2^*\} = \{0, s(x_2 - x_1)\}$ .

*Case4:* the case in which  $\alpha - (7 - 9s)x_1 - x_2 < 0$  and  $\alpha - (7 - 9s)x_2 - x_1 \geq 0$ .

Note that only the region where  $x_1 > x_2$  is relevant in this case. Then,  $\{a_1^*, a_2^*\} = \{s(x_1 - x_2), 0\}$ .

Second, we examine the case in which  $s > 7/9$ . In this case, only the case in which

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<sup>13</sup>The details of the proof are available on request.

$\alpha - (7 - 9s)x_1 - x_2 \geq 0$  and  $\alpha - (7 - 9s)x_2 - x_1 \geq 0$  (i.e., Case 1) is relevant as long as  $s \in [0, 1]$ . Then, when  $x_1 = x_2$ ,  $\{a_1^*, a_2^*\} = \{0, 0\}$ . When  $x_1 > x_2$ ,  $\{a_1^*, a_2^*\} = \{s(x_1 - x_2), 0\}$ . When  $x_1 < x_2$ ,  $\{a_1^*, a_2^*\} = \{0, s(x_2 - x_1)\}$ .

Summarizing these results gives the characterization stated in the text. ■

## The proof of Proposition 1

We examine the investment game between two facility-based firms in the first stage. Following the result of Lemma 1, we examine the two cases, depending on the level of  $s$ . *Case 1:* the case in which  $s \geq 7/9$ .

Let us derive each of facility-based firms' reaction functions. In the following, we examine firm 1's reaction function. Because the access charges set in the second stage depends on the relative magnitude between  $x_1$  and  $x_2$ , we need to examine three cases to derive firm 1's reaction function; the cases in which  $x_1 < x_2$ ,  $x_1 > x_2$ , and  $x_1 = x_2$ .

First, we examine the case in which  $x_1 < x_2$ . In this case,  $a_2^* = s(x_2 - x_1)$  and  $a_1^* = 0$ , and firm 2 is accessed by firm  $S$ . Thus, firm 1's problem is formulated as follows:

$$\underset{x_1}{Max} \pi_1^1(x_1, x_2) = (q_1(a_2^*; x_1, x_2))^2 - I(x_1).$$

Using (2), we derive the following reaction function.

$$x_1^{*1}(x_2) = \frac{(3 - s)(\alpha - x_2)}{8\gamma - (3 - s)^2}. \quad (12)$$

and the associated profit when  $x_2$  is taken as given is:

$$\pi_1^1(x_1^{*1}, x_2) = \frac{\gamma(\alpha - x_2)^2}{2(8\gamma - (3 - s)^2)}. \quad (13)$$

Second, we examine the case in which  $x_1 > x_2$ . In this case,  $a_1^* = s(x_1 - x_2)$  and

$a_2^* = 0$ , and firm 1 is accessed by firm  $S$ . Thus, firm 1's problem is formulated as follows:

$$\underset{x_1}{Max} \pi_1^2(x_1, x_2) = (q_1(a_1^*; x_1, x_2))^2 + a_1^* q_S(a_1^*; x_1, x_2) - I(x_1).$$

Using (1) and (3), we derive the following reaction function.

$$x_1^{*2}(x_2) = \frac{(3 + 2s)\alpha - 3(2s + 1)(1 - s)x_2}{8\gamma - (9 - 4s)}. \quad (14)$$

and the associated profit when  $x_2$  is taken as given is:

$$\pi_1^2(x_1^{*2}, x_2) = \frac{\Omega(x_2)}{4(8\gamma - (9 - 4s))^2}, \quad (15)$$

where

$$\begin{aligned} \Omega(x_2) \equiv & ((4\gamma + 5s)\alpha - (4(1 + s)\gamma + s(2 - 7s))x_2)^2 \\ & + 2s((3 + 2s)\alpha - (8\gamma - (6s^2 - 7s + 6))x_2) \\ & \times ((4\gamma - (6 - s))\alpha - (4(1 - 3s)\gamma - (3s^2 - 14s + 6))x_2) \\ & - 2\gamma((3 + 2s)\alpha - 3(2s + 1)(1 - s)x_2)^2. \end{aligned}$$

Finally, when  $x_1 = x_2$ ,  $a_2^* = a_1^* = 0$ , and each of firms 1 and 2 is accessed by firm  $S$  with probability 0.5. Then, the associated profit when  $x_2$  is taken as given is:

$$\pi_1^3(x_2, x_2) = \frac{1}{16}(\alpha + (2 - s)x_2)^2 - \frac{\gamma}{2}(x_2)^2. \quad (16)$$

Then, firm 1's reaction function is derived by choosing the investment that corresponds with the highest profit among (13), (15), and (16) when  $x_2$  is taken as given. We explain the procedure for the comparison of the profits.

We denote the intersection of (14) and  $x_1 = x_2$  by  $A$  and the associated investment

by  $x^A (= x_1^A = x_2^A)$ . Similarly, we denote the intersection of (12) and  $x_1 = x_2$  by  $B$  and the associated investment by  $x^B (= x_1^B = x_2^B)$ . Using (14) and (12), we ensure that

$$x^A = \frac{(3+2s)\alpha}{8\gamma - (6s^2 - 7s + 6)}, x^B = \frac{(3-s)\alpha}{8\gamma - (3-s)(2-s)}, \text{ and } x^A > x^B.$$

We compare  $\pi_1^1(x_1^{*1}, x_2)$  and  $\pi_1^2(x_1^{*2}, x_2)$  at  $x_2^A$ . First of all, we note that  $\pi_1^2(x_1^{*2}, x_2^A) = \pi_1^3(x_1^A, x_2^A)$  because  $x_1^{*2} = x_1^A$ . On the other hand, because  $x_1^{*1} \equiv \arg \max \pi_1^1(x_1, x_2)$ ,  $\pi_1^1(x_1^{*1}, x_2) \geq \pi_1^1(x_1, x_2)$  for any  $x_1$ . Now, since  $x_1^{*1} \neq x_1^A$  at  $x_2^A$ , we obtain that  $\pi_1^1(x_1^{*1}, x_2^A) > \pi_1^3(x_1^A, x_2^A) = \pi_1^2(x_1^{*2}, x_2^A)$ . Hence, at  $x_2^A$ , firm 1's optimal strategy is  $x_1^{*1}$ .

Similarly, we compare  $\pi_1^1(x_1^{*1}, x_2)$  and  $\pi_1^2(x_1^{*2}, x_2)$  at  $x_2^B$ . We note that  $\pi_1^1(x_1^{*1}, x_2^B) = \pi_1^3(x_1^B, x_2^B)$  because  $x_1^{*1} = x_1^B$ . On the other hand, because  $x_1^{*2} \equiv \arg \max \pi_1^2(x_1, x_2)$ ,  $\pi_1^2(x_1^{*2}, x_2) \geq \pi_1^2(x_1, x_2)$  for any  $x_1$ . Now, since  $x_1^{*2} \neq x_1^B$  at  $x_2^B$ , we obtain that  $\pi_1^2(x_1^{*2}, x_2^B) > \pi_1^3(x_1^B, x_2^B) = \pi_1^1(x_1^{*1}, x_2^B)$ . Hence, at  $x_2^B$ , firm 1's optimal strategy is  $x_1^{*2}$ .

These results indicate that there exists  $\hat{x}_2 \in (x_2^B, x_2^A)$  such that  $\pi_1^1(x_1^{*1}, \hat{x}_2) = \pi_1^2(x_1^{*2}, \hat{x}_2)$ . Therefore, firm 1's reaction function, (R1.1), is derived as follows:

$$(R1.1) \quad x_1^*(x_2) = \begin{cases} \frac{(3-s)(\alpha-x_2)}{8\gamma-(3-s)^2} & \text{for } x_2 \geq \hat{x}_2, \\ \frac{(3+2s)\alpha-3(2s+1)(1-s)x_2}{8\gamma-(9-4s)} & \text{for } x_2 \leq \hat{x}_2. \end{cases}$$

Firm 2's reaction function, (R2.1), is similarly derived by replacing the identification of firms. That is,

$$(R2.1) \quad x_2^*(x_1) = \begin{cases} \frac{(3-s)(\alpha-x_1)}{8\gamma-(3-s)^2} & \text{for } x_1 \geq \hat{x}_1, \\ \frac{(3+2s)\alpha-3(2s+1)(1-s)x_1}{8\gamma-(9-4s)} & \text{for } x_1 \leq \hat{x}_1. \end{cases}$$

These reaction functions of firm 1 and firm 2 are drawn in Figure 1. Then, there are two equilibria in the figure;  $E^{*AAPE1}$  and  $E^{*AAPE2}$ .  $E^{*AAPE1}$  ( $E^{*AAPE2}$ , respectively) represents *the asymmetric access provision equilibria (AAPE)* in which firm 1 (firm 2,

respectively) is accessed by firm  $S$  with probability 1. Simple calculations show that the investments in the equilibria are

$$\begin{aligned} x_1^{*AAPE1} &= \frac{\Phi(s, \gamma)}{\Theta(s, \gamma)} \text{ and } x_2^{*AAPE1} = \frac{\Psi(s, \gamma)}{\Theta(s, \gamma)} \text{ at } E^{*AAPE1}, \\ x_1^{*AAPE2} &= \frac{\Psi(s, \gamma)}{\Theta(s, \gamma)} \text{ and } x_2^{*AAPE2} = \frac{\Phi(s, \gamma)}{\Theta(s, \gamma)} \text{ at } E^{*AAPE2}, \end{aligned}$$

where

$$\begin{aligned} \Theta(s, \gamma) &\equiv (8\gamma - (9 - 4s))(8\gamma - (3 - s)^2) - 3(2s + 1)(1 - s)(3 - s), \\ \Phi(s, \gamma) &\equiv 2(4(3 + 2s)\gamma - (3 - s)(6 - 3s - 4s^2)), \\ \Psi(s, \gamma) &\equiv 2\alpha(3 - s)(4\gamma - (6 - s)). \end{aligned}$$

*Case 2:* the case in which  $s < 7/9$ .

According to Lemma 1, two kinds of equilibrium access charges (i.e., the access charge that allows access by firm  $S$  and the one that induces the foreclosure of firm  $S$ ) can occur if  $x_1$  and  $x_2$  satisfy the following conditions:

$$\alpha - (7 - 9s)x_1 - x_2 \leq 0 \text{ and } \alpha - (7 - 9s)x_2 - x_1 \leq 0 \quad (17)$$

In other words, there are two equilibrium paths when the constraints of (17) are met. When both the two conditions of (17) are not met, only the access charge that allows access by firm  $S$  occurs in equilibrium.

Here, we note that if  $7 - 9s \leq 1$  (i.e.,  $s \geq 2/3$ ), the pair of  $(x_1, x_2)$  that satisfies (17) exhibits  $x_1 + x_2 > \alpha$ , which is irrelevant for our analysis. Thus, for  $s \in [2/3, 7/9)$ , the equilibrium analysis is the same as in the case in which  $s \geq 7/9$ . Therefore, we restrict our attention to the case in which  $s \in [0, 2/3)$  in the following analysis.

As in the case in which  $s \geq 7/9$ , we examine firm 1's strategy to set  $x_1$ . Given  $x_2$ , firm 1 needs to expect firm 2's access pricing strategy if it chooses  $x_1$  that meets the constraints

of (17). In particular, firm 1 has the following two types of expectation regarding firm 2's access pricing strategy under (17). We denote firm 1's threshold investment that meets both the two conditions of (17) given  $x_2$  by  $\overline{x_1}(x_2)$ .

*Expectation 1 (E1)* : If firm 1 sets  $x_1 \geq \overline{x_1}(x_2)$ , firm 2 offers the access charge that induces the foreclosure of firm  $S$ , i.e.,  $a_2^* \geq \overline{a_2}$ .

*Expectation 2 (E2)* : If firm 1 sets  $x_1 \geq \overline{x_1}(x_2)$ , firm 2 offers the access charge that allows access by firm  $S$ , i.e.,  $a_2^* = s(x_2 - x_1)$  or  $a_2^* = 0$ , depending on  $x_1 \gtrless x_2$ .

We should note that, given one of the above expectations, firm 1's optimal strategy must satisfy the following condition to be a candidate of the subgame perfect equilibrium strategies: given  $x_2$ , firm 1's profit under its optimal strategy should be no less than its profit that would be made if firm 2 offered the other equilibrium access charge. For example, suppose that firm 1's optimal strategy under E1 is  $x_1^*(x_2)|_{E1}$  and the associated profit is  $\pi_1(x_1^*(x_2), x_2)|_{E1}$ . Then, we need to check whether  $\pi_1(x_1^*(x_2), x_2)|_{E1} \geq \pi_1(x_1^*(x_2), x_2)|_{E2}$ , where  $\pi_1(x_1^*(x_2), x_2)|_{E2}$  is firm 1's profit given  $x_2$  and  $x_1^*(x_2)|_{E1}$  under E2. This is a deviation check that is critical to derive a subgame perfect equilibrium when there are multiple equilibrium in a subgame.

Before developing the analysis, we prepare firm 1's reaction function under foreclosure. In fact, firm 1's reaction function under foreclosure is

$$x_1^{*4}(x_2) = \frac{4(\alpha - x_2)}{9\gamma - 8}, \quad (18)$$

and the associated profit is

$$\pi_1^4(x_1^{*4}, x_2) = \frac{\gamma(\alpha - x_2)^2}{9\gamma - 8}, \quad (19)$$

if the constraints of (17) are not binding.

#### *The equilibrium under E1*

At first, we analyze the equilibrium under E1. Under E1, given  $x_2$ , firm 2 offers  $a_2^* \geq \overline{a_2}$

if firm 1 sets  $x_1 \geq \overline{x}_1(x_2)$ , whereas firm 2 offers  $a_2^* = s(x_2 - x_1)$  or  $a_2^* = 0$  if firm 1 sets  $x_1 < \overline{x}_1(x_2)$ . The procedure to derive firm 1's optimal investment strategy is as follows: First, we derive its optimal strategy for any  $x_2$  by ignoring the other expectation, E2. Second, we examine a deviation check which is necessary for E2 deviation.

Depending on the locations of  $x_1^{*1}(x_2)$  and  $x_1^{*2}(x_2)$ , we have the following cases:

Case E1-1: when  $x_2^B < x_2^A < \frac{\alpha}{8-9s}$  or  $\gamma > \frac{3}{4}(2s+5)(1-s)$ .

In this case, both  $x_1^{*1}(x_2)$  and  $x_1^{*2}(x_2)$  are inside of  $\alpha - (7-9s)x_1 - x_2 = 0$  and  $\alpha - (7-9s)x_2 - x_1 = 0$  (see Figures 1 and 2). For  $x_2 > \frac{\alpha}{8-9s}$ , if firm 1 chooses from the range of  $x_1 < \overline{x}_1(x_2)$  where  $\overline{x}_1(x_2) = \frac{\alpha-x_2}{7-9s}$ ,  $x_1^{*1}(x_2)$  is optimal. On the other hand, if it chooses from the range of  $x_1 \geq \overline{x}_1(x_2)$ , the optimal strategy depends on whether  $x_1^{*4}(x_2)$  is on the right of  $\alpha - (7-9s)x_1 - x_2 = 0$ . The condition for  $x_1^{*4}(x_2)$  to be on the right of  $\alpha - (7-9s)x_1 - x_2 = 0$  is

$$\frac{9\gamma-8}{4} \leq 7-9s \text{ or } \gamma \leq 4(1-s). \quad (20)$$

Then, it is easy to see that when (20) is met,  $\pi_1^4(x_1^{*4}, x_2) \geq \pi_1^1(x_1^{*1}, x_2)$ . Therefore, under (20),  $x_1^{*4}(x_2)$  is firm 1's optimal strategy for  $x_2 \geq \frac{\alpha}{8-9s}$ .

On the contrary, when  $\gamma > 4(1-s)$ ,  $x_1^{*4}(x_2)$  is not on the right of  $\alpha - (7-9s)x_1 - x_2 = 0$ , we need to check the following condition;

$$\pi_1^1(x_1^{*1}, x_2) \begin{matrix} > \\ < \end{matrix} \tilde{\pi}_1(\overline{x}_1(x_2), x_2),$$

which is equivalent to

$$\Omega(s, \gamma) \begin{matrix} > \\ < \end{matrix} 0$$

where  $\Omega(s, \gamma) \equiv \gamma(7-9s)^2 - (8\gamma - (3-s)^2)(18(1-s)^2 - \gamma)$ . Then, when  $\Omega(s, \gamma) \geq (<) 0$ ,  $x_1^{*1}(x_2)$  ( $\overline{x}_1(x_2)$ ) is firm 1's optimal strategy.

For  $\hat{x}_2 < x_2 \leq \frac{\alpha}{8-9s}$ , it is obvious that  $x_1^{*1}(x_2)$  is optimal. For  $x_2 \leq \hat{x}_2$ , it is also obvious that  $x_1^{*2}(x_2)$  is optimal.

Case E1-2: when  $x_2^B < \frac{\alpha}{8-9s} < x_2^A$  or  $\gamma < \frac{3}{4}(2s+5)(1-s)$  and  $\gamma > \frac{5}{4}(3-s)(1-s)$ .

In this case, we need to examine two cases, depending on whether  $\hat{x}_2 \geq \frac{\alpha}{8-9s}$ . Following the similar procedure as in Case E1-1, we ensure that firm 1's optimal strategy is the same as in Case E1-1.

Case E1-3: when  $\frac{\alpha}{8-9s} < x_2^B < x_2^A$  or  $\gamma < \frac{5}{4}(3-s)(1-s)$ .

Firm 1's optimal strategy is the same as in Case E1-1, except that  $x_1^{*1}(x_2)$  does not appear in this case.

Summarizing the above discussion, firm 1's optimal strategy under E1 is characterized as follows: For  $x_2 \geq \frac{\alpha}{8-9s}$ <sup>14</sup>,

$$\begin{aligned} x_1^{*1}(x_2) & \text{ when } \Omega(s, \gamma) \geq 0, \\ \overline{x}_1(x_2) & \text{ when } \gamma > 4(1-s) \text{ and } \Omega(s, \gamma) < 0, \\ x_1^{*4}(x_2) & \text{ when } \gamma \leq 4(1-s). \end{aligned}$$

Next, we examine the deviation check, i.e., whether firm 1's optimal strategy derived above is not violated by the deviation that is generated by the other expectation, E2.

(i) Consider the case when  $x_1^{*1}(x_2)$  is optimal. Suppose that firm 2 offers  $a_2^* = s(x_2 - x_1^{*1}(x_2))$ .<sup>15</sup>

Then, because firm 1 is not accessed by firm  $S$ , firm 1's profit is exactly the same as  $\pi_1^1(x_1^{*1}, x_2)$ . Hence,  $x_1^{*1}(x_2)$  is definitely firm 1's optimal strategy.

(ii) Consider the case when  $\overline{x}_1(x_2)$  is optimal. Since  $\overline{x}_1(x_2) < x_2$ , firm 2 offers  $a_2^* = s(x_2 - \overline{x}_1(x_2))$  under E2. We derive firm 1's production and the associated profit under E2. In fact, we have

$$\begin{aligned} q_1(a_2^*, \overline{x}_1(x_2), x_2) &= \frac{5(1-s)(\alpha - x_2)}{2(7-9s)}, \text{ and} \\ \pi_1(a_2^*, \overline{x}_1(x_2), x_2) &= \frac{(25(1-s)^2 - 2\gamma)(\alpha - x_2)^2}{4(7-9s)^2}. \end{aligned}$$

<sup>14</sup>For  $x_2 < \frac{\alpha}{8-9s}$ , it is obvious that  $x_1^{*1}(x_2)$  or  $x_1^{*2}(x_2)$  is optimal.

<sup>15</sup>Note that since  $x_1^{*1}(x_2) < x_2$ , firm 2 is certainly accessed by firm  $S$ .

On the other hand, firm 1's profit under E1 is

$$\tilde{\pi}_1(\overline{x}_1(x_2), x_2) = \frac{(18(1-s)^2 - \gamma)(\alpha - x_2)^2}{2(7-9s)^2}.$$

Then, we ensure that  $\tilde{\pi}_1(\overline{x}_1(x_2), x_2) \geq \pi_1(a_2^*; \overline{x}_1(x_2), x_2)$  for all  $s \in [0, 1]$ . Hence,  $\overline{x}_1(x_2)$  is definitely firm 1's optimal strategy.

(iii) Consider the case when  $x_1^{*4}(x_2)$  is optimal. Since  $x_1^{*4}(x_2) < x_2$ , firm 2 offers  $a_2^* = s(x_2 - x_1^{*4}(x_2))$  under E2. We derive firm 1's production and the associated profit under E2. We have

$$\begin{aligned} q_1(a_2^*; x_1^{*4}(x_2), x_2) &= \frac{(9\gamma + 4(1-s))(\alpha - x_2)}{4(9\gamma - 8)}, \text{ and} \\ \pi_1(a_2^*; x_1^{*4}(x_2), x_2) &= \frac{((9\gamma + 4(1-s))^2 - 128\gamma)(\alpha - x_2)^2}{16(9\gamma - 8)^2}. \end{aligned}$$

On the other hand, firm 1's profit under E1 is

$$\pi_1^4(x_1^{*4}, x_2) = \frac{\gamma(\alpha - x_2)^2}{9\gamma - 8}.$$

Then, we ensure that  $\pi_1^4(x_1^{*4}, x_2) > \pi_1(a_2^*; x_1^{*4}(x_2), x_2)$  as long as  $\gamma > \frac{4}{3}(1-s)$ . Hence,  $x_1^{*4}(x_2)$  is definitely firm 1's optimal strategy.

From (i), (ii), and (iii), all of  $x_1^{*1}(x_2)$ ,  $\overline{x}_1(x_2)$ , and  $x_1^{*4}(x_2)$  are firm 1's optimal strategy in the relevant ranges of  $(s, \gamma)$  for  $x_2 \geq \frac{\alpha}{8-9s}$ . For  $x_2 < \frac{\alpha}{8-9s}$ , we can see that  $x_1^{*2}(x_2)$  can be also an optimal strategy in the relevant range of  $(s, \gamma)$ .

Similarly, we ensure that firm 2's optimal strategy is the same as that of firm 1. Therefore, under E1, the subgame perfect equilibrium is derived as shown in Figure 3.

#### *The equilibrium under E2*

Under E2, given  $x_2$ , firm 2 offers  $a_2^* = s(x_2 - x_1)$  or  $a_2^* = 0$  irrespective of whether firm 1 sets  $x_1 \geq \overline{x}_1(x_2)$  or not. Hence, firm 1's optimal strategy is (R1.1).

Let us check the deviation that is generated by E1. To do so, we need to examine three

cases, depending on the locations of  $x_1^{*1}(x_2)$  and  $x_1^{*2}(x_2)$ , as is shown in the analysis of the equilibrium under E1. The result is that (R1.1) cannot be blocked out by the deviation that is generated by E1. Therefore, (R1.1) is certainly firm 1's optimal strategy.

We also ensure that firm 2's optimal strategy is (R2.1). Therefore, under E2, the subgame perfect equilibrium is characterized by AAPE for all ranges of  $(s, \gamma)$ .

Figure 3 summarizes all equilibria in terms of  $(s, \gamma)$ . ■

## The proof of Proposition 2

The equilibria in the third and fourth stages are the same as in the free competition regime. Then, in the second stage, the regulator sets the cost-based access charge, i.e.,  $a^* (= a_1^* = a_2^*) = 0$ , under the assumption that  $a \geq 0$ , as long as  $\alpha$  is sufficiently large.

We examine the investment game between firms 1 and 2 in Stage 1. With  $a^* = 0$ , the conditions under which firm  $S$  accesses firm 1 are

$$x_1 \geq x_2 \text{ and } \alpha - (1 - 3s)x_1 - x_2 \geq 0. \quad (21)$$

Similarly, the conditions under which firm  $S$  accesses firm 2 are

$$x_2 \geq x_1 \text{ and } \alpha - (1 - 3s)x_2 - x_1 \geq 0. \quad (22)$$

The conditions under which firm  $S$  does not enter the market are

$$\alpha - (1 - 3s)x_1 - x_2 < 0 \text{ and } \alpha - (1 - 3s)x_2 - x_1 < 0. \quad (23)$$

Then, we can verify that (23) is irrelevant, because  $x_1 + x_2 \geq \alpha$  for any  $s \in [0, 1]$ . Hence, the foreclosure cannot occur in the access regulation regime.

We examine firm 1's strategy for investment. There are three cases;  $x_1 < x_2$ ,  $x_1 > x_2$ , and  $x_1 = x_2$ .

When  $x_1 < x_2$ , firm 1 is accessed by firm  $S$ . Then, firm 1's problem is

$$\underset{x_1}{Max} \pi_1^{AR1}(x_1, x_2) = \left( q_1^{AR}(a_2^*; x_1, x_2) \right)^2 - I(x_1).$$

Using (2), we derive the following reaction function.

$$x_1^{*AR1}(x_2) = \frac{3(\alpha - (1+s)x_2)}{8\gamma - 9}. \quad (24)$$

and the associated profit when  $x_2$  is taken as given is:

$$\pi_1^{AR1}(x_1^{*AR1}, x_2) = \frac{\gamma(\alpha - (1+s)x_2)^2}{2(8\gamma - 9)}. \quad (25)$$

When  $x_1 > x_2$ , firm 1 is accessed by firm  $S$ . Thus, firm 1's problem is formulated as follows:

$$\underset{x_1}{Max} \pi_1^{AR2}(x_1, x_2) = \left( q_1^{AR}(a_1^*; x_1, x_2) \right)^2 - I(x_1).$$

Using (1), we derive the following reaction function.

$$x_1^{*AR2}(x_2) = \frac{(3-s)(\alpha - x_2)}{8\gamma - (3-s)^2}. \quad (26)$$

and the associated profit when  $x_2$  is taken as given is:

$$\pi_1^{AR2}(x_1^{*AR2}, x_2) = \frac{\gamma(\alpha - x_2)^2}{2(8\gamma - (3-s)^2)^2}, \quad (27)$$

Finally, when  $x_1 = x_2$ , firm 1 is accessed by firm  $S$  with probability 0.5. Then, the associated profit when  $x_2$  is taken as given is:

$$\pi_1^{AR3}(x_2, x_2) = \frac{1}{16}(\alpha + (2-s)x_2)^2 - \frac{\gamma}{2}(x_2)^2. \quad (28)$$

Firm 1's reaction function is derived by choosing the investment level that corresponds

with the highest profit among (25), (27), and (28) when  $x_2$  is taken as given.

We denote the intersection of  $x_1^{*AR1}(x_2)$  and  $x_1 = x_2$  by  $A^{AR}$  and the associated investment by  $x^{ARA}(=x_1^{ARA}=x_2^{ARA})$ . Similarly, we denote the intersection of  $x_1^{*AR2}(x_2)$  and  $x_1 = x_2$  by  $B$  and the associated investment by  $x^{ARB}(=x_1^{ARB}=x_2^{ARB})$ . Using (24) and (26), we ensure that

$$x^{ARA} = \frac{3\alpha}{8\gamma - 3(2-s)}, x^{ARB} = \frac{(3-s)\alpha}{8\gamma - (3-s)(2-s)}, \text{ and } x^{ARA} > x^{ARB}.$$

We also ensure that the slope of  $x_1^{*AR2}(x_2)$  is steeper than that of  $x_1^{*AR1}(x_2)$  in  $(x_1, x_2)$  plane. Then, it is apparent that, at  $x_2^{ARA}$  (or  $x_2 > x_2^{ARA}$ ), firm 1's optimal strategy is  $x_1^{AR*1}$  because firm 1 cannot take  $x_1^{*AR1}(x_2)$  at  $x_2^{ARA}$  (or  $x_2 > x_2^{ARA}$ ). From the same reason, at  $x_2^{ARB}$  (or  $x_2 < x_2^{ARB}$ ), firm 1's optimal strategy is  $x_1^{*AR2}$ . For  $x_2 \in (x^{ARB}, x^{ARA})$ , firm 1 can take neither  $x_1^{*AR1}(x_2)$  or  $x_1^{*AR2}(x_2)$ , so it sets  $x_1 = x_2$ .

In sum, firm 1's reaction function,  $(ARR1)$ , is derived as follows:

$$(ARR1) \quad x_1^{*AR}(x_2) = \begin{cases} \frac{3(\alpha-(1+s)x_2)}{8\gamma-9} & \text{for } x_2 \geq \frac{3\alpha}{8\gamma-3(2-s)}, \\ x_2 & \text{for } \frac{(3-s)\alpha}{8\gamma-(3-s)(2-s)} < x_2 < \frac{3\alpha}{8\gamma-3(2-s)}, \\ \frac{(3-s)(\alpha-x_2)}{8\gamma-(3-s)^2} & \text{for } x_2 \leq \frac{(3-s)\alpha}{8\gamma-(3-s)(2-s)}. \end{cases}$$

Firm 2's reaction function,  $(ARR2)$ , is similarly derived by replacing the identification of firms. That is,

$$(ARR2) \quad x_2^{*AR}(x_1) = \begin{cases} \frac{3(\alpha-(1+s)x_1)}{8\gamma-9} & \text{for } x_1 \geq \frac{3\alpha}{8\gamma-3(2-s)}, \\ x_1 & \text{for } \frac{(3-s)\alpha}{8\gamma-(3-s)(2-s)} < x_1 < \frac{3\alpha}{8\gamma-3(2-s)}, \\ \frac{(3-s)(\alpha-x_1)}{8\gamma-(3-s)^2} & \text{for } x_1 \leq \frac{(3-s)\alpha}{8\gamma-(3-s)(2-s)}. \end{cases}$$

These reaction functions of firm 1 and firm 2 are drawn in Figure 4. From the figure, we ensure that there are multiple equilibria with  $x_1^{*ARE} = x_2^{*ARE} \in [x^{ARB}, x^{ARA}]$  in the access regulation regime. In each of the equilibria,  $a_1^{*ARE} = a_2^{*ARE} = 0$ , and each of

facility-based firms are accessed by firm  $S$  with probability 0.5, irrespective of the degree of spillover and the investment cost. ■

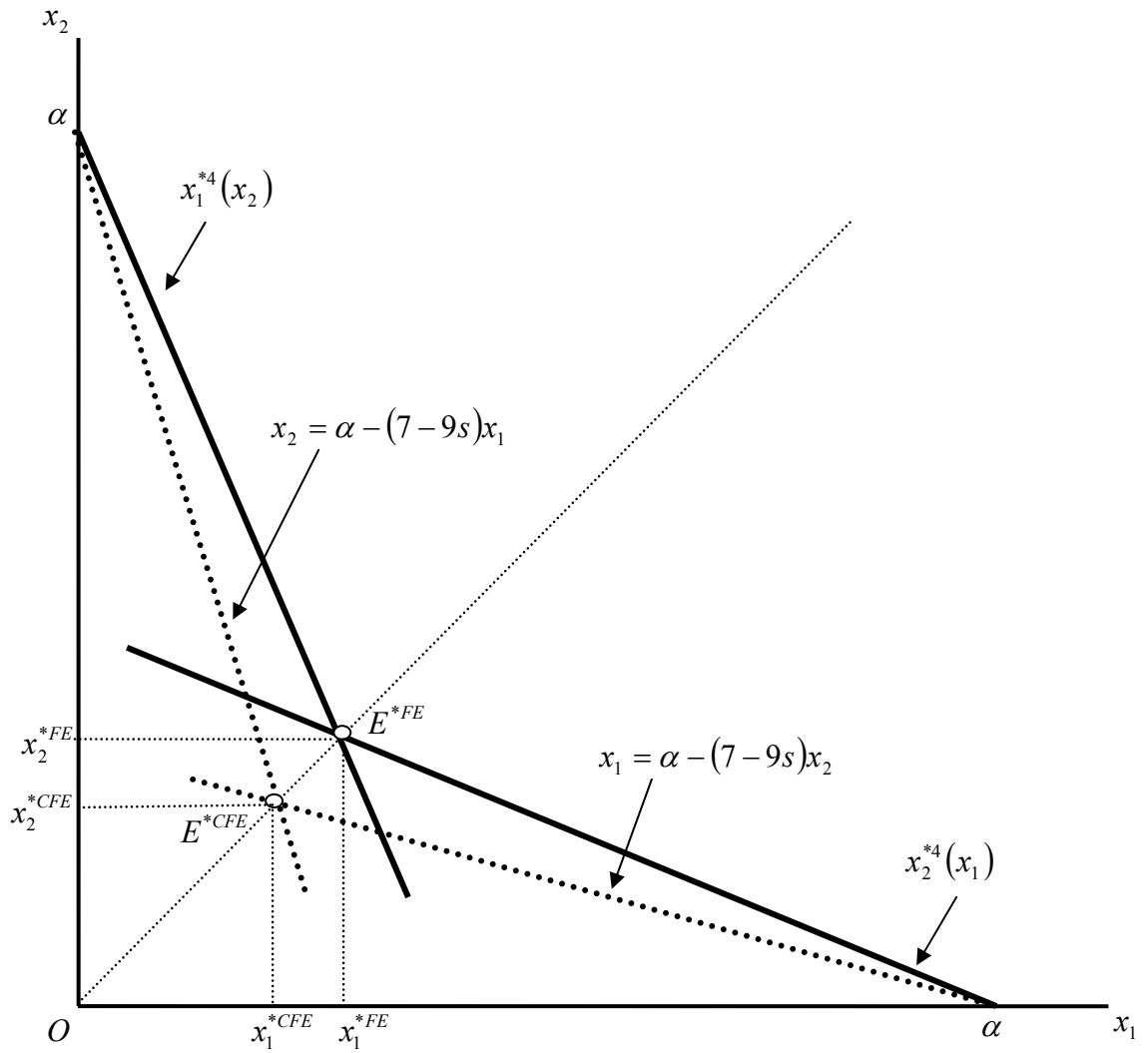
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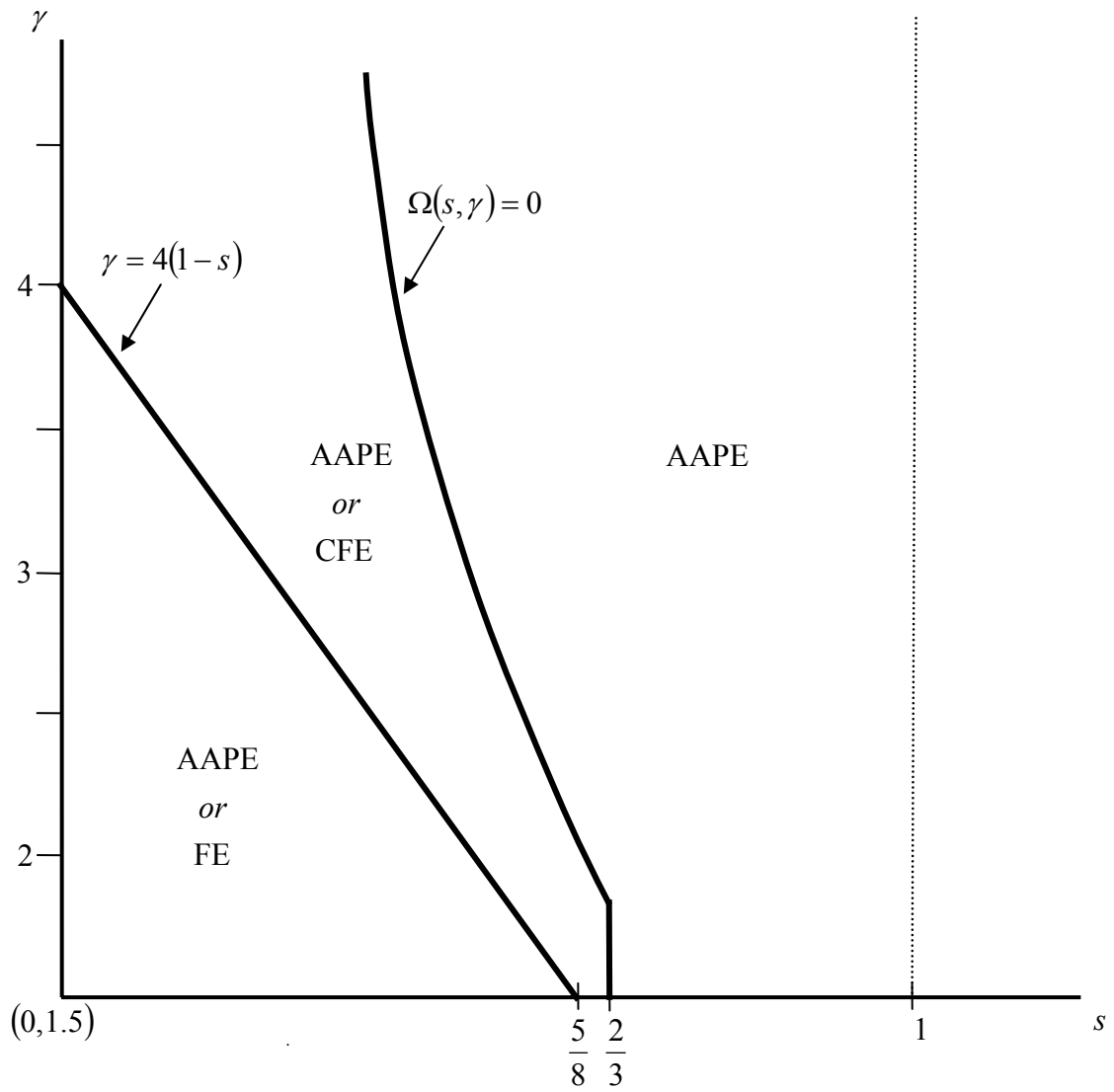
Firm 1's (firm 2's, respectively) reaction function is the solid parts of  $x_1^{*1}(x_2)$  and  $x_1^{*2}(x_2)$  ( $x_2^{*1}(x_1)$  and  $x_2^{*2}(x_1)$ , respectively).



**Figure 2 Foreclosure Equilibrium (FE) and Constrained Foreclosure Equilibrium (CFE)**

**Note:**

Firm 1's (firm 2's, respectively) reaction function is  $x_1^*(x_2)$  ( $x_2^*(x_1)$ ), respectively).



**Figure 3 Equilibria in the Free Competition Regime**

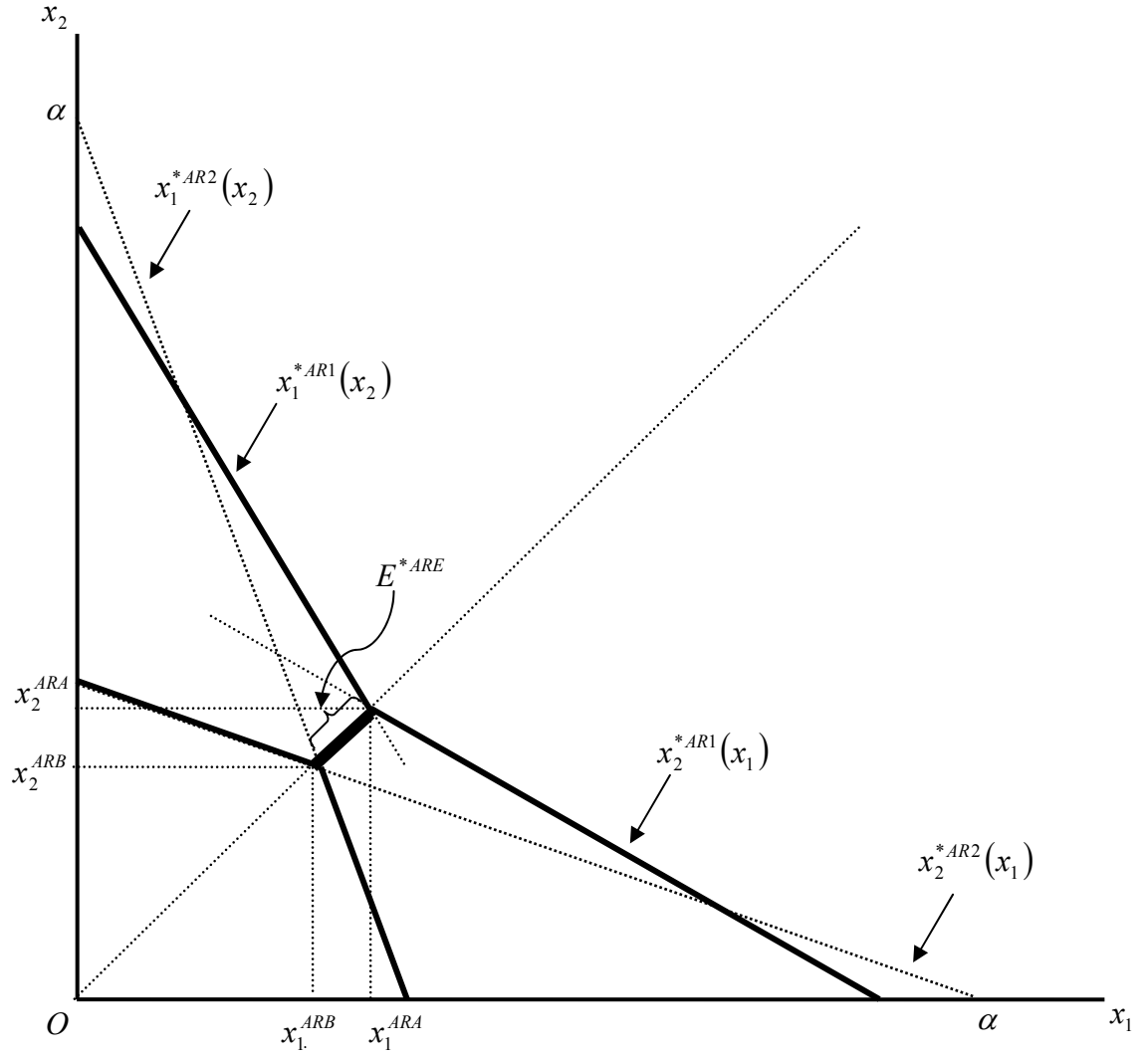
**Notes:**

AAPE: Asymmetric Access Provision Equilibrium

FE: Foreclosure Equilibrium

CFE: Constrained Foreclosure Equilibrium

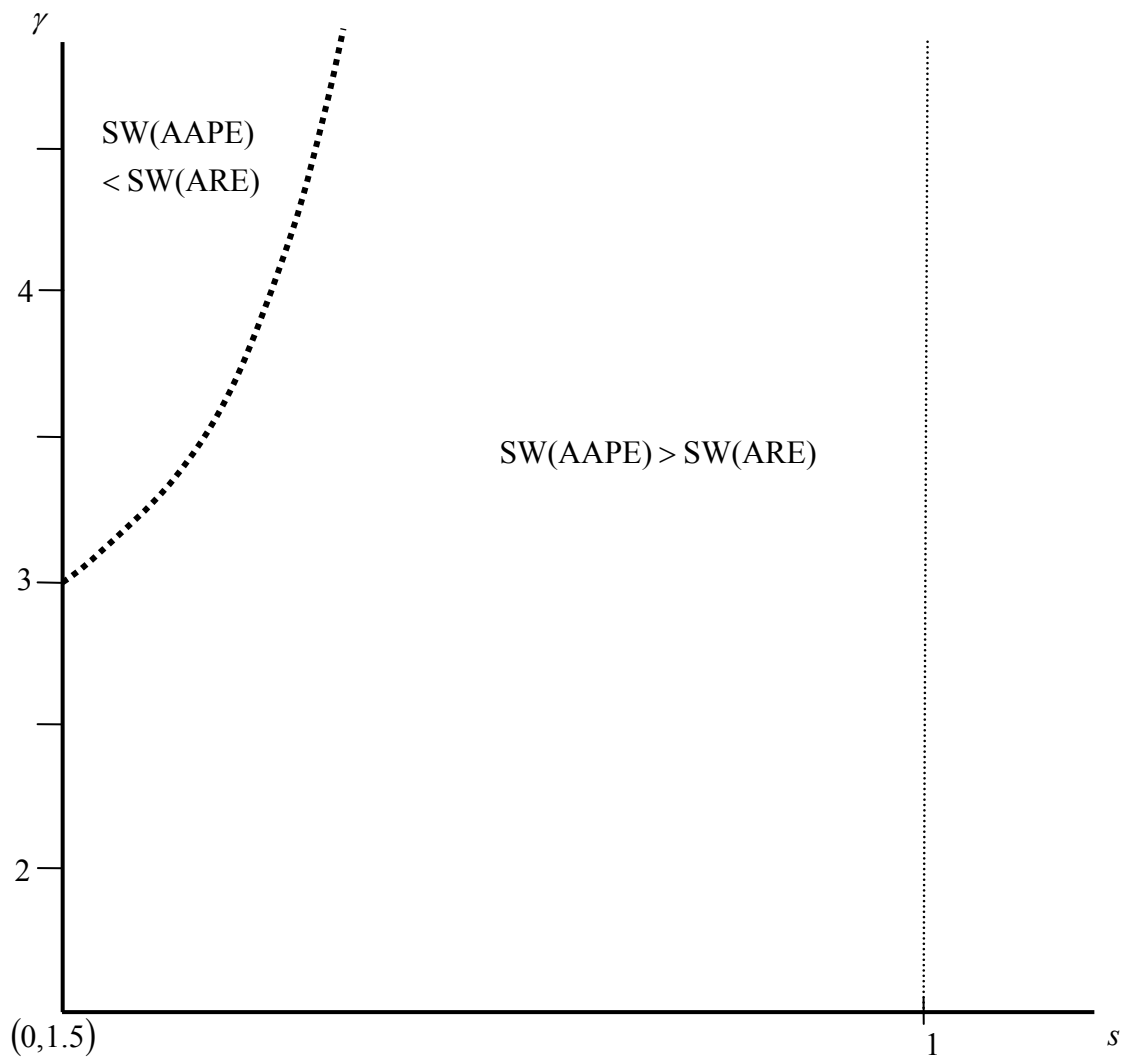
$$\Omega(s, \gamma) \equiv \gamma(7 - 9s)^2 - (8\gamma - (3 - s)^2)(18(1 - s)^2 - \gamma)$$



**Figure 4 Access Regulation Equilibrium (ARE)**

**Note:**

Firm 1's (firm 2's, respectively) reaction function is the solid parts of  $x_1^{*AR1}(x_2)$  and  $x_1^{*AR2}(x_2)$  ( $x_2^{*AR1}(x_1)$  and  $x_2^{*AR2}(x_1)$ , respectively) and  $x_1 = x_2$  for  $x_2 \in [x_2^{ARB}, x_2^{ARA}]$  ( $x_2 = x_1$  for  $x_1 \in [x_1^{ARB}, x_1^{ARA}]$ , respectively).

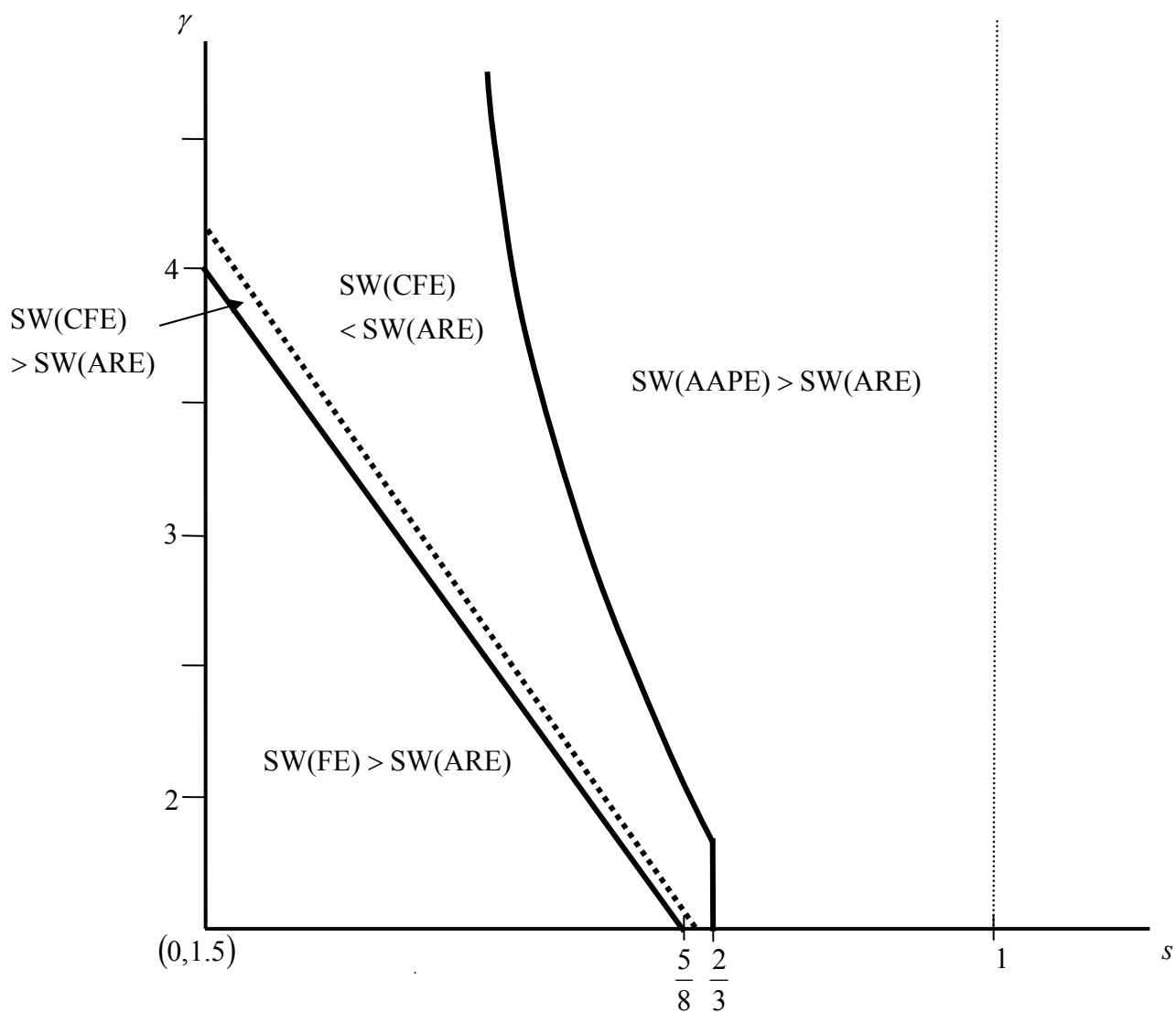


**Figure 5-1 Welfare Comparison between AAPE and ARE**

**Notes:**

SW(AAPE): Social welfare in the asymmetric access provision equilibrium

SW(ARE): Social welfare in the access regulation equilibrium



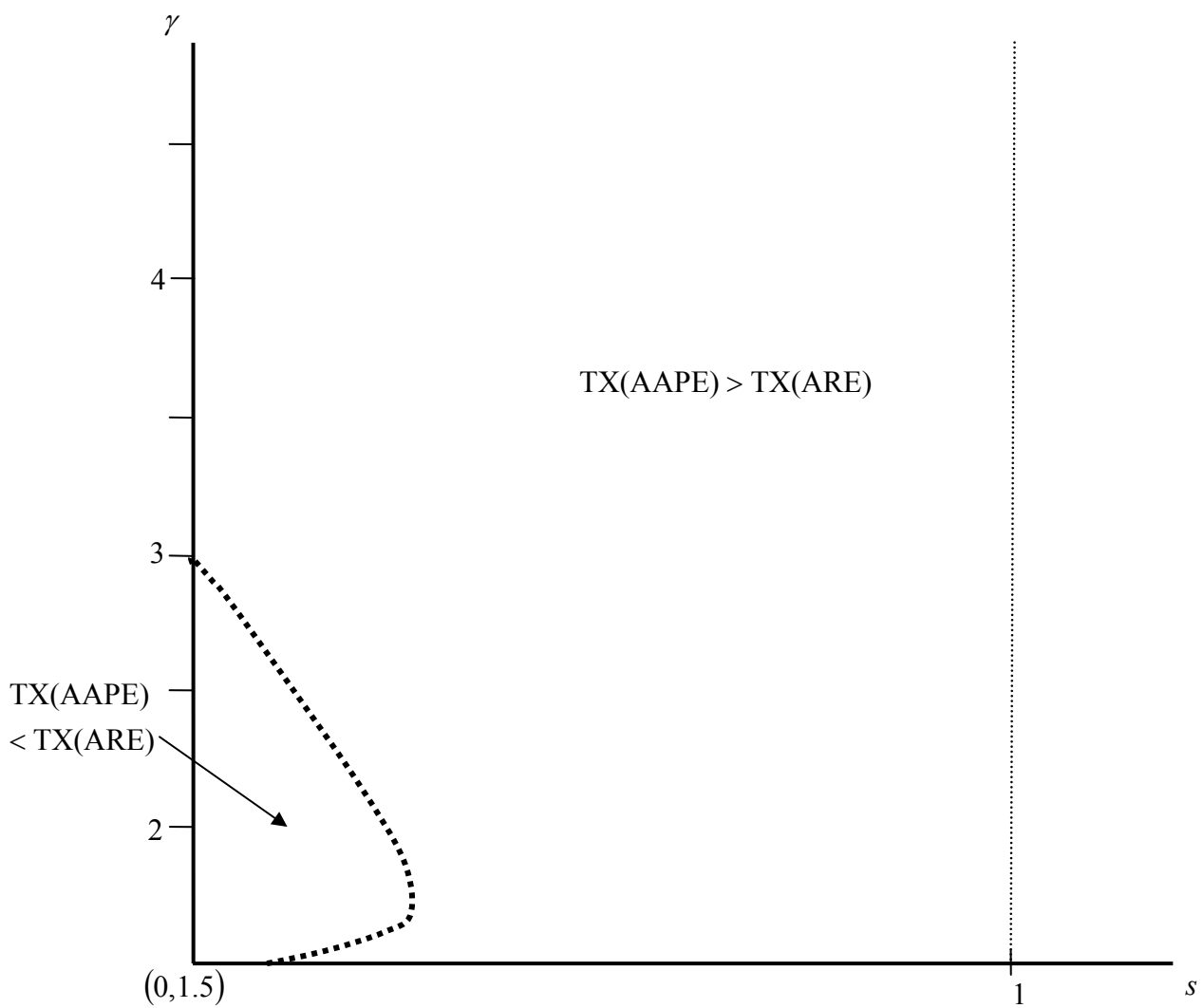
**Figure 5-2 Welfare Comparison between FE (or CFE) and ARE**

**Notes:**

SW(FE): Social welfare in the foreclosure equilibrium

SW(CFE): Social welfare in the constrained foreclosure equilibrium

SW(ARE): Social welfare in the access regulation equilibrium

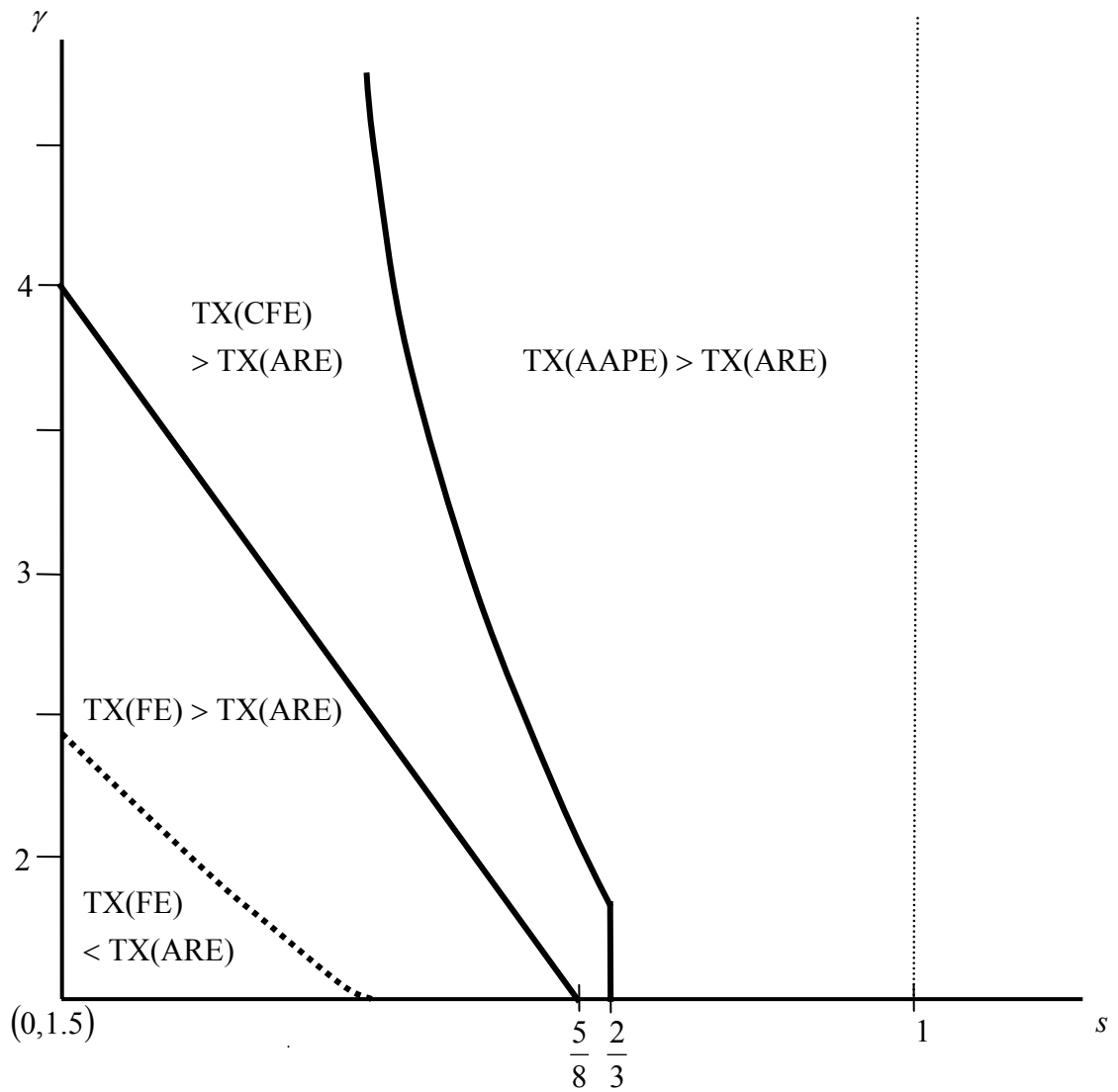


**Figure 6-1 Investment Comparison between AAPE and ARE**

**Notes:**

$TX(AAPE)$ : Total investment in the asymmetric access provision equilibrium

$TX(ARE)$ : Total investment in the access regulation equilibrium



**Figure 6-2 Investment Comparison between FE (or CFE) and ARE**

**Notes:**

TX(FE): Total investment in the foreclosure equilibrium

TX(CFE): Total investment in the constrained foreclosure equilibrium

TX(ARE): Total investment in the access regulation equilibrium