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Network Investment and Competition with Access-to-Bypass*

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Abstract

This paper examines firms' incentives to make irreversible investments under an open access policy with stochastically growing demand. Using a simple model, we derive an access-to-bypass equilibrium. Analysis of the equilibrium confirms that the introduction of competition in network industries makes a firm's incentive to make investments greater than those of a monopolist. We then show that a change in access charges induces a trade-off in social welfare. That is, a decrease in the access charge expands the social benefit flow in the access duopoly, and deters not only the introduction of a new network facility, but also a positive network externality generated by the construction of an additional bypass network. The feasibility of socially optimal investment timing is then discussed.

Keywords: Open access policy; Investment; Real options; Network facility; Access charge

JEL classification: D92; G13; L43; L51

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1 Introduction

Since the early 1980s, competition has been introduced in public utility industries (such as telecommunications, natural gas and electricity) in OECD countries to increase efficiency and innovation. An important example of competition policy is the *open access policy*, which grants entrants that do not have a network facility access to an incumbent's network.[1] Nevertheless, these industries remain characterized by large sunk costs of investment, and increasing uncertainty in business environments. In addition, competition lowers the expected profit flow from investment, so that it tends to delay investment. Hence, the open access policy may reduce incentives for a *facility-based entry*. Given the potentially adverse effects on incentives, the open access policy has been reconsidered in some countries. For example, in 2003, the Federal Communications Commission (FCC) adopted new rules concerning the network unbundling obligations of incumbent local phone carriers, with the aim of providing incentives for carriers to invest in broadband.[2] That is, policy makers who have recommended the introduction of competition or open access policies are uncertain about how effective competition in public utility or network industries is in enhancing social welfare.

Note that an access charge in an open access policy is a crucial factor that affects both the profit of firms and social benefits in network industries. However, we should not ignore its effect on the timing of investment in infrastructure in these industries, especially when demand is expanding. In telecommunications, in addition to the traditional telephone, several kinds of communication devices, such as mobile telephones and Internet telephony, expand demand in the industry. For example, the annual growth rate of information services and telecommunications industries in Japan has been around 4% since 1997,[3] which suggests that more broadband networks are required. Similarly, demand for natural gas has been increased by environmental protection, which suggests greater demand for broader gas pipeline networks in the future. With growing demand, infrastructure investment can be stimulated by access charges or other policy instruments in an open access environment.

This paper analyzes the competitive environment in public utility or network industries by focusing on the effects of access charges on firms' incentives to invest when there is stochastically growing demand. We employ *a real options approach* to examine issues related to investment because the industries are characterized by

[1] See OECD (2001) for details.

[2] The new rules do not require unbundling of hybrid loops and fiber-to-the-home (FTTH) loops for both broadband and narrowband services. Michael K. Powell, the chairman of FCC, states: "Today's decision makes significant strides to promote investment in advanced architecture and fiber by removing impeding unbundling obligations."

[3] See InfoCom Research, Inc.(2003).

large sunk costs of investment and increasing demand (or cost) uncertainty. The real options approach features irreversibility of investment under uncertainty. It highlights the option value of delaying an investment decision. In fact, a decision on the timing of irreversible investment under uncertainty is crucial for firms in public utility or network industries.

Specifically, the real options approach is useful when a player has a sequential opportunity of investment timing. As is well-known, public utility industries comprise a production facility and a network facility. (For example, in the electricity industry, a plant for generating electricity is the production facility, whereas transmission and local distribution wires are network facilities.) In the industries, then, an entrant or follower has a sequential opportunity of investment timing; that of a construction of a *bypass* or another network facility. This is because an important characteristic of network industries is approval for a common use of network facilities. Since network (or essential) facilities are characterized by large sunk costs, their common use is recommended from a social point of view, as long as congestion problems do not occur. An entrant's decision to construct a bypass may be controversial with respect to improving welfare. In that case, the real options approach is suitable for examining the properties of an entrant's sequential investment decision (i.e., *from access to bypass*) because the application of a simple net present value (NPV) approach cannot provide adequate understanding of an entrant's incentives to construct a bypass when there is uncertainty and investment is irreversible. With an NPV approach, one would characterize the entrant's decision about whether (or when) to construct a bypass by comparing the net present value of profit under access with that under use of the bypass. However, such an approach would be inappropriate because it ignores the option value of delaying additional investment in the bypass. This is the main reason for adopting the real options approach to examine the incentives for investment in network industries. To sum up, this approach is useful for studying network industries and, in particular, for studying the effect of regulatory policies on the performance of these industries.

Using a simple model of an option exercise game, we examine a following issue; an effect of open access policy on the timing of investment or entry. To examine that issue, we first derive an *access-to-bypass equilibrium* by allowing an entrant to access an incumbent's network facility. In particular, we characterize the entrant's sequential investment timing for the construction of an additional network facility, having accessed the incumbent's network, in terms of an access charge and the level of network investment cost. Analysis of the equilibrium confirms that the introduction of competition in network industries makes a firm's incentive to invest greater than that of a monopolist. That is, in an access-to-bypass equilibrium, an open access policy leads a firm to enter earlier than if there were no competition. This implies that an open access policy provides a strong pre-emptive incentive to a firm, irrespective of the level of the access charge, as long as the access-to-bypass equilibrium holds. We then show that a change in the access charge induces a trade-off in social welfare. That is, a decrease in the access charge expands social benefit flow in the access duopoly, and deters not only the introduction of a new network facility, but also a positive network externality generated by the construction of an additional bypass network. This trade-off occurs even when there is a usage access charge, since the trade-off is due to its effect on profit flows in the access duopoly.

While many studies have addressed the access pricing problem in public utility industries in static economic environments,[4] some papers have examined the effect of access pricing on the incentive to invest in network facilities. Examples are Sidak and Spulber (1997), Gans and Williams (1999) and Gans (2001), who considered incentives to invest in infrastructure when there is no uncertainty.[5] The effect of uncertainty on irreversible investment has been formally examined by Biglaiser and Riordan (2000). However, they neither analyzed a game between an incumbent and an entrant nor allowed an entrant to construct a bypass. A book edited by Alleman and Noam (1999) contains some existing debate on real options approach applied to access pricing. We formally analyze the option exercise game in public utility or network industries by focusing on an entrant's decision to make an additional investment in bypass construction when there is stochastically growing demand.

In the next section, we describe the framework of a real options model for an imperfectly competitive network industry. In section 3, we derive the access-to-bypass equilibrium in which the entrant first adopts an access strategy and then converts to a bypass strategy. In section 4, we examine the properties of the equilibrium. Section 5 concludes the paper.

2 The Model

There are two risk-neutral firms, $i = 1, 2$, which plan to enter a network industry, such as electricity, telecommunications or natural gas. The network industry needs two types of facility to serve their customers: a production facility and a network facility. Each firm has the opportunity to invest in both types of facility, and the investment decisions in each type are assumed to be irreversible. The investment cost for the production facility is $I^e > 0$, and that for the network facility is $I^m > 0$. Both I^e and I^m are sunk costs.

Investments in the two types of facility may be undertaken simultaneously or

[4] See Armstrong (2002) for an elegant survey for the access pricing problems.

[5] A special issue of *Telecommunications Policy* is also devoted to "Access pricing investment and entry in telecommunications". See especially Valletti (2003) in that issue for a discussion of the relationship between access pricing and investment incentives.

sequentially. A firm constructs the production facility at cost I^e, and at the same time or in the next stage, the network facility is built at an additional cost of I^m. However, not all firms need to invest in the network facility, provided that at least one firm maintains the facility. That is, the firm without a network facility may utilize the existing network facility to distribute products. The firm that initially enters the market with both production and network facilities is a *leader*, whereas the other firm, which may or may not have a network facility, is a *follower*. We assume that the follower can access the existing network facility through a usage access charge, $v > 0$, which is given for each firm and determined by a policy maker.[6] When the follower uses the leader's existing network facility, the leader incurs an access (or usage) cost for the network facility, c, which is the same as the cost of its own production. Moreover, the follower, having access to the leader's network facility, may invest in the construction of its own network facility in the future. For simplicity, production costs other than access costs are assumed to be zero.

We assume that the two firms compete in a market for a homogeneous good produced in the network industry. The profit flows of the firms are uncertain because the firms face an aggregate exogenous industry shock. The profit flow of a firm is represented by $\pi = Y\Pi(N)$, where Y is the aggregate exogenous shock, $N = 0, 1, 2$ is the number of active firms and $\Pi(N)$ is interpreted as the non-stochastic part of the firm's profit flow at the industry equilibrium.

Y evolves exogenously and stochastically according to a geometric Brownian motion, with drift given by the following expression:

$$dY_t = \alpha Y_t dt + \sigma Y_t dW,$$

where $\alpha \in (0, r)$ is the drift parameter measuring the expected growth rate of Y, r is the risk-free interest rate, $\sigma > 0$ is a volatility parameter and dW is the increment of a standard Wiener process, where $dW \sim N(0, dt)$. Note that $\alpha > 0$ implies that the firm's profit flow $\pi = Y\Pi(N)$ is enhanced stochastically.

A firm's profit flow in the monopolistic equilibrium is represented by $Y\Pi(1)$. When the two firms are active in the market, we must distinguish between two duopolistic market structures: 'access duopoly', in which the follower has access to the leader's network facility; and 'bypass duopoly', in which the follower maintains its own network facility. Let $Y\Pi^L(2; v)$ represent the profit flow of the leader in the access duopoly equilibrium, and let $Y\Pi^F(2; v)$ represent the profit flow of the follower. Similarly, $Y\Pi(2)$, which is the same for the leader and follower, represents the profit flow in the bypass duopoly equilibrium.

[6] Regulated access pricing in some public utility industries is based on a two-part pricing formula (i.e., a usage charge and a fixed charge). For analytical simplicity, we analyze only a usage charge in this paper. See Hori and Mizuno (2003) for an analysis of a lump-sum or fixed access charge.

The following relationship is assumed to hold.

Assumption 1 (i) $\Pi(1) > \Pi(2)$ and $\Pi(1) > \Pi^i(2;v)$ $(i = L, F)$, (ii) $\Pi(2) \geq \Pi^F(2;v)$, (ii) $\Pi^L(2;v) \underset{(<)}{\geq} \Pi^F(2;v)$ if $v \underset{(<)}{\geq} c$, (iii) $\frac{\partial \Pi^L(2;v)}{\partial v} > 0$, (iv) $\frac{\partial \Pi^F(2;v)}{\partial v} < 0$.

In (i), it is reasonable to assume that the equilibrium profit $\Pi(N)$ is a decreasing function of N. The assumption of (ii) is based on the notion that additional supply of the network facility improves the quality of goods or generates a positive network externality. For example, a decrease in the probability of blackout may be generated by the construction of another transmission wire in a local electricity market, or the capability to provide high calorie gas may be due to the construction of additional gas pipelines in a gas market. In telecommunications, the construction of another broadband cable can benefit the population of Internet users, which in turn increases the firms' profits. It is easy to imagine that this assumption guarantees the follower's incentive to construct a bypass facility. Note that we do not exclude the case in which $\Pi^L(2;v)$ is greater than $\Pi(2)$. This occurs when the access charge v is so high that it generates more profit for a leader than is generated by a positive network externality. As shown below, there exists a unique equilibrium (on which we focus) not only in that case, but also when the leader's profit in the access duopoly is less than that in the bypass duopoly.

We restrict our attention to Markov strategies for a firm's decision about when to enter (or when to invest): each firm's decision depends only on the state variable Y. As an equilibrium concept fro the game, we use a subgame perfect equilibrium.

The follower has three possible strategies. First, the follower may want access to the network facility constructed by the leader forever to save on investment costs, I^m. Second, the follower may want to construct its own network facility to save on an access payment. Another possibility is that the follower initially has access to the leader's network facility, but then decides to construct its own network facility.[7] We refer to these three alternatives as the '*access strategy*', the '*bypass strategy*' and the '*access-to-bypass strategy*', respectively. The preference of the follower may depend on the conditions relating to the level of investment costs, the equilibrium profit under product market competition, the level of the access charge, and so on. In the next section, we examine the follower's choice of strategy before deriving the equilibrium of the game.

[7] Yet another possibility is that the follower first constructs its own network plant and then uses the leader's plant by paying an access charge. However, we can ignore this possibility because network investment and the access payment are irreversible.

3 The Access-to-Bypass Equilibrium

We derive the equilibria of the game described in section 2.

3.1 The follower's choice of strategy

First, we must consider the follower's strategy choice when the follower is allowed to not only have access to the leader's network facility, but also to construct its own network facility. As mentioned in the previous section, in this environment, the follower has three alternative strategies: the access strategy, the bypass strategy and the access-to-bypass strategy. We ask the question, under what conditions does the follower choose one strategy over the others? We note that the follower's choice can only be appropriately determined by the real options approach under irreversible investment and uncertainty. The standard net present value approach ignores the option value of waiting generated by the irreversibility of the two types of investment that the follower can make.

To answer the question, we first derive the value of each project before obtaining the values of the three strategies.

When the access project is undertaken, its value is:

$$V^{A}(Y) = \frac{Y\Pi^{F}(2;v)}{r-\alpha}. \tag{1}$$

When the bypass project is undertaken, the value of the project is:

$$V^{B}(Y) = \frac{Y\Pi(2)}{r-\alpha}. \tag{2}$$

Using (1) and (2), we can define the value of *the transition project*, $\Delta V(Y)$, which is the difference between the values of the bypass project and the access project:

$$\Delta V(Y) \equiv V^{B}(Y) - V^{A}(Y) = \frac{Y\Delta\Pi(2;v)}{r-\alpha}, \tag{3}$$

where $\Delta\Pi(2;v) \equiv \Pi(2) - \Pi^{F}(2;v)$ is referred to as the *incremental profit flow from access to bypass.*

Suppose that the bypass project is undertaken. Then, there must be a trigger point Y^{B*}, at which the bypass project begins. Defining the option value of the transition project and using the value-matching and smooth-pasting conditions, we derive the trigger point Y^{B*}:[8]

$$Y^{B*} = \frac{\beta_1}{\beta_1 - 1} \frac{r - \alpha}{\Delta\Pi(2; v)} I^m. \tag{4}$$

Next, we derive the trigger point Y^{A*} at which the access project begins. Note that, when the bypass project is allowed, the *effective* value of the access project includes not only its own project value, but also the option value of the transition project. Hence, defining the option value of the access project and using the value-matching and smooth-pasting conditions, we determine the trigger point Y^{A*}.[9]

$$Y^{A*} = \frac{\beta_1}{\beta_1 - 1} \frac{r - \alpha}{\Pi^F(2; v)} I^e. \tag{5}$$

From (4) and (5), an increase in uncertainty deters not only the follower's entry by access, but also its construction of a bypass facility. That is, $\partial Y^{A*}/\partial\sigma > 0$ and $\partial Y^{B*}/\partial\sigma > 0$, since β_1 is a decreasing function of the volatility parameter σ.[10]

The derivation clarifies which strategy is adopted by the follower. When $Y^{B*} < +\infty$ and $(0 <) Y^{A*} \leq Y^{B*}$, the follower adopts the access-to-bypass strategy. When $Y^{B*} = +\infty$ and $Y^{A*} (> 0)$, the follower adopts the access strategy. When $Y^{B*} < Y^{A*}$, the follower adopts the bypass strategy. The following lemma states the conditions under which each strategy is adopted by the follower.

Lemma 1 *Under* $\Delta\Pi(2; v) > 0$ of *Assumption 1(i), the follower adopts the access-to-bypass strategy (the bypass strategy) if and only if:*

$$\Pi(2) \leq (>) \left(1 + \frac{I^m}{I^e}\right) \Pi^F(2; v). \tag{6}$$

Proof. Abbreviated. ■

When an incremental profit flow from access to bypass is positive, i.e., when $\Delta\Pi(2; v) > 0$, the access strategy is not adopted by the follower. This is because

[8] The derivation follows a standard technique in the real options literature. See Dixit and Pindyck (1994).

[9] We can ensure that the trigger point Y^{A*} is the same when the bypass construction is not allowed, which means that the option value of the transition project does not affect the trigger point for the access project Y^{A*}. This is because the option to enter the market by access includes the option value of the transition project. In fact, the option value of the transition project is canceled out in the process of deriving Y^{A*}:

[10] See pp.143-144 of Dixit and Pindyck (1994) for the effect of σ on β_1.

the aggregate shock Y evolves according to a geometric Brownian motion such that it has the expected growth rate α.

3.2 The equilibrium

In this subsection, we focus on the case in which the follower adopts the access-to-bypass strategy. We do so because this is a general case in the sense that it includes two actions of the follower and shows some peculiar characteristics of network industries.

When the follower chooses the access-to-bypass strategy, the value function is as follows.

$$V_F^{AB}(Y) = \begin{cases} \left(\frac{Y}{Y^{A*}}\right)^{\beta_1} \left\{ \frac{Y^{A*}\Pi^F(2;v)}{r-\alpha} - I^e + \left(\frac{Y^{A*}}{Y^{B*}}\right)^{\beta_1} \left[\frac{Y^{B*}\Delta\Pi(2;v)}{r-\alpha} - I^m \right] \right\} & if \;\; Y < Y^{A*} \\ \frac{Y\Pi^F(2;v)}{r-\alpha} - I^e + \left(\frac{Y}{Y^{B*}}\right)^{\beta_1} \left[\frac{Y^{B*}\Delta\Pi(2;v)}{r-\alpha} - I^m \right] & if \;\; Y^{A*} \leq Y < Y^{B*} \\ \frac{Y\Pi(2)}{r-\alpha} - (I^e + I^m) & if \;\; Y^{B*} \leq Y \end{cases} \tag{7}$$

The trigger points $Y^{A*} > 0$ and $Y^{B*} > 0$ are (5) and (4), respectively.

Next, we consider the leader's value function when the follower adopts the access-to-bypass strategy. In that case, the value function of the leader is derived as follows.

$$V_L^{AB}(Y) = \begin{cases} \frac{Y\Pi(1)}{r-\alpha}\left[1 - \left(\frac{Y}{Y^{A*}}\right)^{\beta_1 - 1}\right] + \left(\frac{Y}{Y^{A*}}\right)^{\beta_1} \left\{ \frac{Y^{A*}\Pi^L(2;v)}{r-\alpha}\left[1 - \left(\frac{Y^{A*}}{Y^{B*}}\right)^{\beta_1 - 1}\right] + \left(\frac{Y^{A*}}{Y^{B*}}\right)^{\beta_1} \frac{Y^{B*}\Pi(2)}{r-\alpha} \right\} - (I^e + I^m) & if \;\; Y < Y^{A*} \\ \frac{Y\Pi^L(2;v)}{r-\alpha}\left[1 - \left(\frac{Y}{Y^{B*}}\right)^{\beta_1 - 1}\right] + \left(\frac{Y}{Y^{B*}}\right)^{\beta_1} \frac{Y^{B*}\Pi(2)}{r-\alpha} - (I^e + I^m) & if \;\; Y^{A*} \leq Y < Y^{B*} \\ \frac{Y\Pi(2)}{r-\alpha} - (I^e + I^m) & if \;\; Y^{B*} \leq Y \end{cases} \tag{8}$$

Let us focus on the asymmetric leader-follower equilibrium, which we refer to as the '*access-to-bypass equilibrium*'. To guarantee the existence and uniqueness of the equilibrium, it is sufficient to ensure that $V_L^{AB}(Y^{A*}) > V_F^{AB}(Y^{A*})$ and that the difference between the leader's value and the follower's value decreases monotonically. When the investment cost for the network facility is small relative to the cost for the production facility and when the access charge is sufficiently high that it offsets the benefit generated by a positive network externality for the leader, there exists a unique equilibrium in which the follower enters the market by access and then builds its own bypass facility in the future. We summarize this result in the following proposition.

Proposition 1 *There exists a unique access-to-bypass equilibrium in which the leader's trigger point* Y_L^{AB} *is characterized by*

$$\begin{array}{lll} V_L^{AB}(Y) < V_F^{AB}(Y) & if & Y < Y_L^* \\ V_L^{AB}(Y) = V_F^{AB}(Y) & if & Y = Y_L^* \\ V_L^{AB}(Y) > V_F^{AB}(Y) & if & Y \in \left(Y_L^*, Y^{B*}\right) \\ V_L^{AB}(Y) = V_F^{AB}(Y) & if & Y \geq Y^{B*}, \end{array}$$

under the condition that

$$I^m - \frac{\beta_1}{\beta_1 - 1}\frac{\Pi^{LF}(2;v)}{\Pi^F(2;v)}I^e < (\beta_1 - 1)\left(\frac{\Delta\Pi(2;v)}{\Pi^F(2;v)}\frac{I^e}{I^m}\right)^{\beta_1}\left[1 - \frac{\beta_1}{\beta_1 - 1}\frac{\Pi^{LF}(2;v)}{\Delta\Pi(2;v)}\right]I^m < -\frac{\Pi^{LF}(2;v)}{\Pi^F(2;v)}\frac{I^e}{I^m}. \tag{9}$$

where $\Pi^{LF}(2;v) \equiv \Pi^L(2;v) - \Pi^F(2;v)$.

Proof. Abbreviated. ■

[Insert Figure 1]

Figure 1 shows the access-to-bypass equilibrium. For $Y \in [0, Y_L^*)$ where Y_L^* is the trigger point at which the leader enters the market, the two firms do not enter the market. For $Y \in \left[Y_L^*, Y^{A*}\right)$, the leader earns monopoly profits. For $Y \in \left[Y^{A*}, Y^{B*}\right)$, the follower has access to the leader's network facility. For $Y \in \left[Y^{B*}, +\infty\right)$, the follower constructs its own network facility.

4 Properties of the Equilibrium

4.1 The effect of competition

Using a real options approach, and comparing the optimal strategy of a monopolist with the optimal strategy of a leader in duopoly, Nielsen (2002) showed that, even with irreversible investment and uncertainty, competition induces firms to invest earlier. We can extend this result to the access-to-bypass equilibrium derived in the previous section.

As a benchmark, we present the investment trigger point of a monopolist, which is given by

$$Y^* = \frac{\beta_1}{\beta_1 - 1} \frac{r - \alpha}{\Pi(1)} \left(I^e + I^m\right). \tag{10}$$

We then derive the following proposition.

Proposition 2 *The leader in an access-to-bypass equilibrium enters the market earlier than a monopolist.*

Proof. Abbreviated. ■

To prove Proposition 2, we show in the Appendix that $V_L^{AB}(Y^*) > V_F^{AB}(Y^*)$ for $Y \in (0, Y^{A*})$. The condition that $V_L^{AB}(Y^{A*}) > V_F^{AB}(Y^{A*})$, which guarantees the existence and uniqueness of the access-to-bypass equilibrium, plays a crucial role in the proof of the proposition. For the condition to be satisfied, as we explained before stating Proposition 1, the access charge v must exceed the access cost c, or the investment cost for the network facility I^m must be small. Then, the leader's value is higher than that of the follower at $Y \in (Y_L^*, Y^{B*})$, which means that both firms have strong pre-emptive incentives under competition.

The meaning of this result warrants a detailed explanation. Note that the introduction of competition reduces a firm's profit flow, i.e., from $\Pi(1)$ to $\Pi^i(2; v)$ $(i = L, F)$, which lowers a firm's incentive to enter. In a real options approach, the effect of the decrease in profit flow on the timing of entry is more severe than in an NPV approach. This is because the option value of waiting is due to irreversible investment and uncertainty, which should be added to the net present value of profit.[11] However, each firm has a strategic motive to extract a monopoly rent, i.e., it has a pre-emptive incentive. Hence, the result implies that the pre-emptive incentive for being a leader dominates the effect of a decrease in the profit flow, even if the option value of waiting is realized. This *pre-emptive-incentive-domination effect* was also found by Nielsen (2002). We extend his result to an open access competitive environment.[12]

Furthermore, the follower in the access-to-bypass equilibrium might also enter the market earlier than a monopolist.

Corollary 1 *When* $\Pi(1) < \left(1 + \frac{I^m}{I^e}\right)\Pi^F(2; v)$, *the follower in the access-to-bypass equilibrium enters the market earlier than a monopolist.*

Proof. Comparing Y^{A*} with Y^* proves this point. ■

[11] This point is made by the formula for the trigger point (e.g., Y^*) by the multiplication of $\frac{\beta_1}{\beta_1 - 1}$ (> 1).

[12] Grenadier (2002) also emphasized the impact of competition on an exercise strategy of investment in an N-player Cournot-Nash competition.

Note that, even when the follower's profit flow under access duopoly is less than that of a monopolist (i.e., $\Pi^F(2;v) < \Pi(1)$) as stated in Assumption 1(i), the follower may enter the market earlier than a monopolist. This is because the follower is allowed to access the leader's network facility by paying an access charge v. In fact, this can be the case when the investment cost for a network facility is small relative to the cost of a production facility, and when the follower's profit is not too small. For example, for $\beta_1 = 2$, under a set of $\{I^m = 0.5I^e,\ \Pi^F(2;v) = 0.7\Pi(1),\ \Pi(2) = \frac{2.8}{3}\Pi(1)\}$, which guarantees the existence and uniqueness of the equilibrium, the follower enters the market earlier than a monopolist.

4.2 The effect of the access charge

In the previous subsection, we showed that the introduction of competition makes the leader enter earlier than a monopolist even when there is irreversible investment under uncertainty. However, the access charge also affects the firm's incentive to enter an open-access competitive environment. We examine the effect of the access charge on the trigger points in the access-to-bypass equilibrium.

Proposition 3 *(i)* $\partial Y_L^*/\partial v < 0$, *(ii)* $\partial Y^{A*}/\partial v > 0$, *(iii)* $\partial Y^{B*}/\partial v < 0$.

Proof. Abbreviated. ■

From Proposition 3, a unit access charge can affect the investment timing of firms. In particular, a decrease in the unit access charge can induce the follower to enter the market early through access and construct its bypass facility late, and induces the leader to enter late. That is, in the access-to-bypass equilibrium, a change in the access charge has a positive effect on the follower's entry with access, but has a negative effect on the leader's entry and the introduction of bypass construction.

The result and its welfare implications are intuitive. When the access charge decreases, consumers cannot be served early through the construction of a new network facility by a leader (such as a new broadband cable in a rural area) and neither can they enjoy positive network externalities early. However, they can enjoy a longer access duopoly equilibrium in which a social benefit flow is higher than in a monopoly equilibrium.[13] In addition, a decrease in the unit access charge usually increases the social benefit flow *itself* in the access duopoly equilibrium, through an increase in the equilibrium quantity. Therefore, there is a trade-off in the policy of changing the access charge, which gives rise to a dilemma for a policy maker.

[13] A social benefit flow is formally defined in the next subsection.

5 Concluding Remarks

In this paper, we have investigated the effects of access charges on firms' incentives to invest in network public-utility industries when investment is irreversible and there is uncertainty. Since the industries are characterized by large sunk costs for investment with stochastically growing demand, we employed a real options approach to examine some policy issues in an open-access competitive environment.

Using a simple model, we derived an *access-to-bypass equilibrium* by allowing an entrant the opportunity to access an incumbent's network facility. In particular, we characterized an entrant's sequential investment timing for the construction of an additional network facility, having accessed the incumbent's network, in terms of an access charge and the level of network investment costs. Analysis of the equilibrium confirmed that the introduction of competition in network industries makes a firm's incentive to invest greater than that of a monopolist. That is, in an access-to-bypass equilibrium, a firm enters earlier in an open access policy if there is competition. We then showed that a change in the access charge induces a trade-off in social welfare. That is, a decrease in the access charge expands social benefit flow in the access duopoly equilibrium, and deters the introduction of a new network facility and a positive network externality generated by the construction of an additional bypass network. This trade-off occurs even when there is only a usage access charge through its effect on profit flows in the access duopoly equilibrium.

In our model, the firms' investment was only a zero/one decision. If we allow them to choose the size of investment, then access may clearly affect their decision in a strong way. For example, the leader may choose a small network capacity so that the follower cannot access it when entering the market. In addition, if the leader can choose the quality level of a network capacity, he may try to degrade the entrant's ability to use the network. These are the issues of strategic entry deterrence that has received a great deal of play in the policy arena and would be an interesting avenue for future research.

One may think that regulatory policy tools other than lump-sum subsidies or taxes could be used to achieve the optimal investment timing. For example, if the access charge depends on the state, such as $v(Y)$, it may be possible to achieve the optimum. However, in that case, firms' profits would be non-linear functions of Y, which would complicate the analysis. In addition, voluntary agreements on access charges between network providers and access seekers may induce an approximate social optimum. The search for policy tools that will achieve the social optimum is also an important issue for future research.

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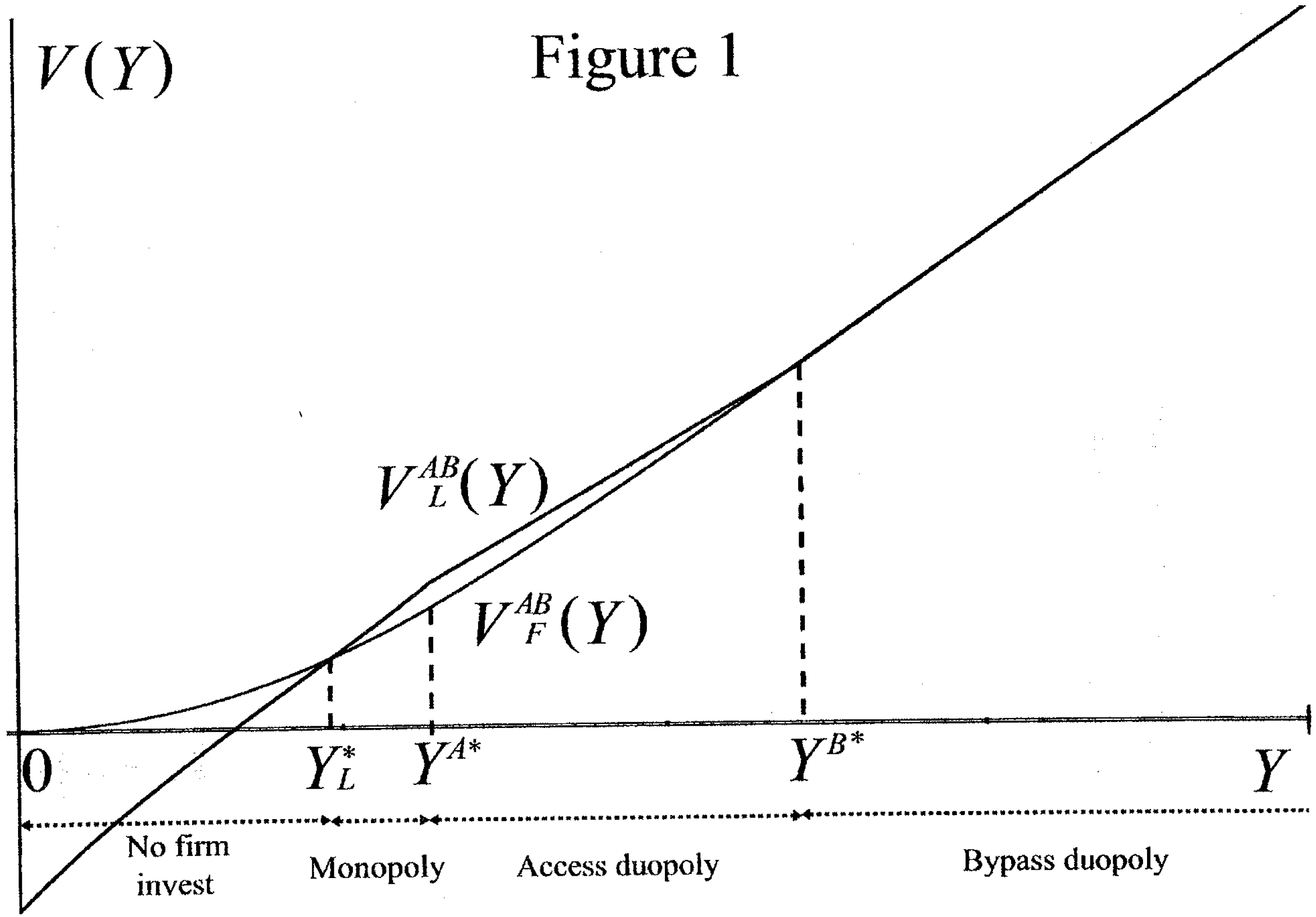
Figure 1



V(Y)
V^AB_L(Y)
V^AB_F(Y)
0
Y*_L
Y^A*
Y^B*
Y
No firm invest
Monopoly
Access duopoly
Bypass duopoly