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Abstract: In a liberalized telecommunications market, an incumbent with an old-technology network possesses several advantages over an entrant without such a network when entering a new-technology network market. An asymmetric access charge regulation for two such asymmetric firms stimulates competitive investment in the new-technology network. However, asymmetry of regulations between the two firms is transitional, and is removed once the entrant is fully competitive with respect to the incumbent. We show that an entrant with a cost disadvantage has an incentive to invest in the new-technology network as a leader under uncertainty over deregulation of an asymmetric access charge. These results fit well with the findings of previous empirical work. Moreover, we investigate the effects of intensity of deregulation of asymmetric access charges on competitive investment strategies.

Keywords: Investment timing; Asymmetric access charge; Deregulation; telecommunications.

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1 Introduction

In a liberalized telecommunications market, an incumbent with an old-technology network possesses several advantages for entering a new-technology network market over any entrant without an old-technology network. This creates an asymmetric market environment, so there may be a role for an asymmetric regulation between asymmetric firms. In policy debates, the desirability of an asymmetric regulation has been recognized. Such an asymmetric access charge accords with legislation in many developed countries.[1] Table 1 shows the access charge difference among Japanese mobile telephone firms.[2] We can see that the regulation of access in Japan differs between operators with and without significant market power.

[Insert Table 1 about here]

Several studies have examined the effect of asymmetric access charges on investment incentive and welfare (consumer and producer surpluses). Carter and Wright (2003) and Peitz (2005) have explored the role of asymmetric regulation in an asymmetric market in a static model. Shibata and Yamazaki (2010) has extended the static models to a dynamic model. The main insight of all these papers is that asymmetric access charge regulation is a powerful policy instrument because it stimulates investment and increases consumer surplus.

To the best of our knowledge, however, there has *not* been an examination of deregulation of asymmetric access charge regulation in the telecommunications market. To address such questions in a recently liberalized market, we must consider asymmetric regulation as transitional and access charges are deregulated once the entrant is fully competitive with respect to the incumbent. Thus, in considering the role of an asymmetric regulation between asymmetric firms, we must consider deregulation.

This paper examines investment timing under uncertainty over deregulation of asymmetric access charges in a recently liberalized telecommunications market. In addition, we investigate the effects of uncertainty in removal of asymmetric access charge regulation on competitive investment and consumer and producer surpluses. Our main contribution

[1] See Cave (1997) for privatization and liberalization of network utilities. See Laffont et al. (1997) and Armstrong (1998) for networks access pricing.

[2] In the cellular phone industry of Japan, NTT Docomo corporation is an incumbent, and KDDI corporation and Softbank corporation are the second and third firms to enter the market, respectively. The market share of the three firms is over 95 percent. The access charge is calculated based on equipment cost and the number of subscribers according to NTT docomo and KDDI estimates. Regulation of the access charge is imposed on the NTT docomo and KDDI with a market's share of more than 25 percent.

is to show how deregulation uncertainty influences strategic investment timing and total social welfare.

Our paper provides several important results. First, asymmetric access charge regulation may lead the entrant to enter the new market as a leader, even under the potential threat of the removal of the asymmetric regulation. This result accords with empirical findings concerning the cellular phone market in Japan. For example, the Japanese entrant KDDI corporation began to provide a service based on the CDMA (Code Division Multiple Access) technology, which we refer to as "3G (third generation) technology" earlier than the Japanese incumbent, NTT Docomo corporation. Second, asymmetric access charge regulation may accelerate investment. This result leads to an increase in consumer surplus and a decrease in producer surplus. However, note that the investment may be delayed when the asymmetric access charge is too small or too large. The reason is that extremely slight or large asymmetry in access charge regulation may cause an extremely asymmetric competitive advantage for a firm. Third, we consider the effect of deregulation intensity on investment timing. When the intensity of deregulation is too weak and too strong, the investment trigger is increased (i.e., the investment is decreased) because a competitive market environment would be weakened. The implication for the regulation authority is that the extremes of deregulation should not be used to stimulate investment. Fourth, we consider the case where only one of the firms misunderstands the intensity of deregulation. Interestingly, this misunderstanding may cause an increase in the total welfare, defined as the sum of the consumer and producer surpluses. Finally, the pre-emptive investment trigger as a leader is lowest when the competitive market environment between two firms is completely symmetric, causing the consumer and producer surpluses to be at the highest and the lowest levels, respectively. Thus, the more intense the market competitive environment is, the higher (lower) is the consumer (producer) surplus. These results accord well with those of previous empirical studies (e.g., Harris et al. (1995) and Laffont and Tirole (2000)).

The remainder of the paper is organized as follows. Section 2 describes the setup of the model. Section 3 examines strategic investment between two asymmetric firms under uncertain removal of asymmetric regulations. In particular, using the numerical examples, we consider the effects of asymmetric regulation. Section 4 analyses the effects of deregulation uncertainty. Section 5 describes the case where only one of the firms misunderstands the deregulation intensity. Sections 4 and 5 include a discussion of the implications for telecommunication policy. Section 6 concludes.

2 Model

In this section, we begin with a description of the setup. We then provide the value functions for leader and follower firms.

2.1 Setup

Consider two asymmetric firms: an incumbent (Firm I) and an entrant (Firm E). These two firms have an investment opportunity in the new-technology network, assuming the incumbent has an old-technology network. Both the incumbent and the entrant are risk neutral.

The cash flow to provide the new-technology network service depends on the number of operating firms in the market (i.e., monopoly or duopoly). The investment yields an instantaneous cash flow, $D_j X_t$, where $D_j > 0$ is a constant quantity depending on the number of operating firms, j ($j \in \{1, 2\}$). We assume $D_1 > D_2$. This condition implies that an investment is less profitable when more firms have invested.[3] Also, let X_t be the price at time t given by the following geometric Brownian motion:

$$\mathrm{d}X_t = \mu X_t \mathrm{d}t + \sigma X_t \mathrm{d}z_t, \quad X_0 = x > 0,$$

where z_t denotes the standard Brownian motion, and $\mu > 0$ and $\sigma > 0$ are positive constants. For convergence, we assume that $\mu < r$ where $r > 0$ denotes a risk-free interest rate.[4]

We assume that the cost expenditure to undertake the investment, which we denote by K_k ($k \in \{\mathrm{I}, \mathrm{E}\}$), is completely sunk. Here, we assume the following relationship between the cost expenditure of the two firms.

Assumption 1 (Asymmetric cost structure between two firms): $K_{\mathrm{E}} > K_{\mathrm{I}} > 0$.

This assumption means that the incumbent has a cost advantage over the entrant. That is, the difference $K_{\mathrm{E}} - K_{\mathrm{I}} > 0$ reflects the incumbent's advantage and gives rise to an asymmetric market environment. Similar asymmetries have also been considered by Carter and Wright (2003) and Peitz (2005). Obviously, unless the incumbent has an advantage, there would be no reason to analyse asymmetric regulation.

Once the market is a duopoly, each firm has to access the network facility that the rival firm constructs with paying an access charge. For example, Firm k can access the

[3] The assumption is reasonable in such a competitive market. It is exactly the same as in Weeds (2002) and Shibata and Yamazaki (2010).

[4] Often, μ is assumed to be $\mu \in (\sigma^2/2, r)$, where $\sigma^2/2 < \mu$ is necessary for a meaningful expected time to exercise the investment option. See Shibata (2009) for greater detail.

network facility that Firm k' provides by paying an access charge $v_{k'} > 0$ for any k ($k, k' \in \{\mathrm{I}, \mathrm{E}\}, k \neq k'$). We assume the following relationship between them.

Assumption 2 (Asymmetric access charge regulation between two firms): $v_{\mathrm{E}} = h > l = v_{\mathrm{I}} > 0$.

This assumption implies that there is an asymmetric access charge regulation in an asymmetric market environment in that the incumbent has a cost advantage, which is considered reasonable in an asymmetric market environment. In policy discussions, the need for asymmetric regulation under an asymmetric market environment has been recognized (see, e.g., Peitz (2005)). Such asymmetric access charge regulation is in accordance with legislation in many developed countries. For example, the regulation of access in the European Union and Japan differ between operators with and without significant market power (see Table 1 for asymmetric access charges in the Japanese mobile phone market).

Asymmetric regulation between two firms is transitional and deregulation occurs once the entrant is competitive with respect to the incumbent. In practice, because the need for deregulation in situations of asymmetric regulation has been recognized, asymmetric access charge regulation will be abolished in the near future. We assume that the time of deregulation, T, follows an exponential distribution with respect to $\lambda \geq 0$, and T is independent of X_t. In other words, we model such an asymmetric regulation termination by supposing that the firm faces an exogenous termination driven by a Poisson process with intensity λ.[5]

Finally, throughout the paper, it is assumed that the current state variable $X_0 = x$ is sufficiently low for the investment not to be undertaken immediately. We call the firm that invests first the *leader* and the other firm the *follower*.

2.2 Value functions

In this subsection, we consider value functions of the leader and the follower. The value functions are derived backwards. We begin with the derivation of the follower's value function. We then derive the leader's value function given the follower's value function. Henceforth we denote the rival of Firm k as Firm k'. For example, we have $k' = \mathrm{I}$ when $k = \mathrm{E}$ and vice versa.

[5]Timing of deregulation is decided privately by the regulation authority. On the other hand, the firms face uncertainty about deregulation because they do not know when regulations will apply. Thus, it is natural for the firms that the timing of deregulation follows a random variable.

2.2.1 Follower's value function

Let $x^*_{\mathrm{F}k}$ be the investment trigger for a follower, where the subscript "Fk" indicates Firm k's strategy as a follower F. Mathematically, we define the stopping times by $\tau^*_{\mathrm{F}k} := \inf\{t \geq 0; X_t \geq x^*_{\mathrm{F}k}\}$ for any k ($k \in \{\mathrm{I}, \mathrm{E}\}$). Let $F^{\mathrm{a}}_k(x;\lambda)$ and $F^{\mathrm{o}}_k(x;\lambda)$ denote Firm k's value function as a follower *after* and *before* investment, respectively. Here, the superscripts "a" and "o" represent the adoption and option values of the investment, respectively.

The follower's value function after investment, $F^{\mathrm{a}}_k(x;\lambda)$, is defined by

$$F^{\mathrm{a}}_k(x;\lambda) := \mathbb{E}^x\Big[\int_0^T \mathrm{e}^{-ru}(D_2X_u + v_k - v_{k'})\mathrm{d}u + \int_T^{+\infty} \mathrm{e}^{-ru} D_2 X_u \mathrm{d}u\Big], \quad k \in \{\mathrm{I}, \mathrm{E}\}, \tag{1}$$

where $\mathbb{E}^x[\cdot]$ denotes the expectation operator with the joint distribution of the stochastic process X_t starting with $X_0 = x$ and the exponentially distributed random variable T. The value expressed in the equation (1) consists of two components. The first and second components capture the present value of the revenue *before* and *after* the time of deregulation T, respectively.

Under standard arguments (see, e.g., Dixit and Pindyck (1994)), $F^{\mathrm{a}}_k(x;\lambda)$ in (1) is given by

$$F^{\mathrm{a}}_k(x;\lambda) = \mathbb{E}^x\Big[\int_0^{+\infty} \mathrm{e}^{-ru} D_2 X_u \mathrm{d}s + \int_0^T \mathrm{e}^{-ru}(v_k - v_{k'})\mathrm{d}u\Big] = \frac{D_2}{r-\mu}x + \frac{v_k - v_{k'}}{r+\lambda}, \tag{2}$$

in which we have used Fubini's theorem and the additivity of integrals. The value given in (2) consists of two components. The first term measures the present value of adopting the investment. The second term captures the value added or subtracted by an asymmetric access charge regulation. In particular, $F^{\mathrm{a}}_{\mathrm{I}}(x;\lambda)$ and $F^{\mathrm{a}}_{\mathrm{E}}(x;\lambda)$ are given by

$$F^{\mathrm{a}}_{\mathrm{I}}(x;\lambda) = \frac{D_2}{r-\mu}x + \frac{l-h}{r+\lambda}, \qquad F^{\mathrm{a}}_{\mathrm{E}}(x;\lambda) = \frac{D_2}{r-\mu}x + \frac{h-l}{r+\lambda},$$

respectively. Here, asymmetric regulation $h \geq l > 0$ leads to the follower's value of the entrant being larger than that of the incumbent. Importantly, $F^{\mathrm{a}}_{\mathrm{I}}(x)$ and $F^{\mathrm{a}}_{\mathrm{E}}(x)$ are increasing and decreasing in λ, which is one of the key parameters in our model.

It is also worth pointing out that $F^{\mathrm{a}}_k(x;\lambda)$ in (2) satisfies the conditions

$$\lim_{\lambda\uparrow+\infty} F^{\mathrm{a}}_k(x;\lambda) = \frac{D_2}{r-\mu}x, \qquad \lim_{\lambda\downarrow 0} F^{\mathrm{a}}_k(x;\lambda) = \frac{D_2}{r-\mu}x + \frac{v_k - v_{k'}}{r}. \tag{3}$$

These results are intuitively clear. As the intensity λ increases without limit, the expected time of the deregulation approaches 0. On the other hand, as the intensity λ decreases to 0, the expected arrival time tends to infinity, meaning that the deregulation is never expected to occur. We can rewrite $F^{\mathrm{a}}_k(x;\lambda)$ in (2) as

$$F^{\mathrm{a}}_k(x;\lambda) = \frac{\lambda}{r+\lambda}F^{\mathrm{a}}_k(x;+\infty) + (1 - \frac{\lambda}{r+\lambda})F^{\mathrm{a}}_k(x;0). \tag{4}$$

Note that $\mathbb{E}^x[\mathrm{e}^{-\lambda T}] = \lambda/(r+\lambda)$ can be regarded as the probability of deregulation occurring. The value (4) can be expressed as the weighted average of the extreme values in (3). This is similar to the study by Alvarez and Stenbakca (2001).

We define the follower's value function *before* investment $F_k^{\mathrm{o}}(x;\lambda)$ by

$$F_k^{\mathrm{o}}(x;\lambda) := \sup_{\tau_{\mathrm{F}k}} \mathbb{E}^x[\mathrm{e}^{-r\tau_{\mathrm{F}k}}(F_k^{\mathrm{a}}(X_{\tau_{\mathrm{F}k}};\lambda) - K_k)], \quad k \in \{\mathrm{I}, \mathrm{E}\}. \tag{5}$$

Note that $F_k^{\mathrm{o}}(x;\lambda)$ in (5) is the option value of $F_k^{\mathrm{a}}(x;\lambda)$ in (4). The value $F_k^{\mathrm{o}}(x;\lambda)$ is obtained as

$$F_k^{\mathrm{o}}(x;\lambda) = \Big(\frac{x}{x_{\mathrm{F}k}^*(\lambda)}\Big)^{\beta}(F_k^{\mathrm{a}}(x_{\mathrm{F}k}^*;\lambda) - K_k), \tag{6}$$

where $\beta = 1/2 - \mu/\sigma^2 + \sqrt{(\mu/\sigma^2 - 1/2)^2 + 2r/\sigma^2} > 1$ and

$$x_{\mathrm{F}k}^*(\lambda) = \frac{\beta}{\beta-1}\frac{r-\mu}{D_2}\Big(K_k - \frac{v_k - v_{k'}}{r+\lambda}\Big). \tag{7}$$

In particular, $x_{\mathrm{FI}}^*(\lambda)$ and $x_{\mathrm{FE}}^*(\lambda)$ are

$$x_{\mathrm{FI}}^*(\lambda) = \frac{\beta}{\beta-1}\frac{r-\mu}{D_2}\Big(K_{\mathrm{I}} + \frac{h-l}{r+\lambda}\Big), \quad x_{\mathrm{F}k}^*(\lambda) = \frac{\beta}{\beta-1}\frac{r-\mu}{D_2}\Big(K_{\mathrm{E}} - \frac{h-l}{r+\lambda}\Big),$$

respectively. The former is decreasing and the latter increasing in λ. It is straightforward to obtain

$$x_{\mathrm{F}k}^*(\lambda) = \frac{\lambda}{r+\lambda}x_{\mathrm{F}k}^*(+\infty) + \Big(1 - \frac{\lambda}{r+\lambda}\Big)x_{\mathrm{F}k}^*(0), \tag{8}$$

for any k ($k \in \{\mathrm{I}, \mathrm{E}\}$). Exactly the same as in (4), the optimal threshold $x_{\mathrm{F}k}^*$ in (8) can be expressed as the weighted average of the extreme thresholds.

2.2.2 Leader's value function

Let $x_{\mathrm{L}k}$ be the investment trigger as a leader. Here, the subscript "Lk" indicates for Firm k's strategy as a leader L. Mathematically, we define the stopping times as $\tau_{\mathrm{L}k} := \inf\{t \geq 0; X_t \geq x_{\mathrm{L}k}\}$ for any k ($k \in \mathrm{I}, \mathrm{E}\}$). Let L_k^{a} and L_k^{o} denote the Firm k's value function as a leader *after* and *before* investment, respectively.

The leader's value function *after* investment, $L_k^{\mathrm{a}}(x;\lambda)$, is defined by

$$L_k^{\mathrm{a}}(x;\lambda) := \mathbb{E}^x\Big[\int_0^{\tau_{\mathrm{F}k'}} \mathrm{e}^{-ru}D_1X_u\mathrm{d}u + \int_{\tau_{\mathrm{F}k'}}^{\tau_{\mathrm{F}k'}^*+T} \mathrm{e}^{-ru}(D_2X_u + v_k - v_{k'})\mathrm{d}u + \int_{\tau_{\mathrm{F}k'}^*+T}^{+\infty} \mathrm{e}^{-ru}D_2X_u\mathrm{d}u\Big], \quad k \in \{\mathrm{I}, \mathrm{E}\}, \tag{9}$$

where $X_0 = x$. The value $L_k^{\mathrm{a}}(x)$ consists of three components. The first term is the present value of the payoff in a monopoly. The second and third terms are the present value of the payoff *before* and *after* deregulation in a duopoly, respectively. The leader's value function, $L_k^{\mathrm{a}}(x;\lambda)$, is given by

$$L_k^{\mathrm{a}}(x;\lambda) = \frac{D_1}{r-\mu}x + \Big(\frac{x}{x_{\mathrm{F}k'}^*(\lambda)}\Big)^{\beta}\Big(\frac{D_2-D_1}{r-\mu}x_{\mathrm{F}k'}^*(\lambda) + \frac{v_k - v_{k'}}{r+\lambda}\Big), \tag{10}$$

where $X_0 = x$.[6] The leader's value function *before* investment, $L_k^{\mathrm{o}}(x;\lambda)$, is defined by

$$L_k^{\mathrm{o}}(x;\lambda) := \sup_{\tau_{\mathrm{L}k}} \mathbb{E}^x[\mathrm{e}^{-r\tau_{\mathrm{L}k}}(L_k^{\mathrm{a}}(X_{\tau_{\mathrm{L}k}};\lambda) - K_k)], \quad k \in \{\mathrm{I},\mathrm{E}\}. \tag{11}$$

Note that the value $L_k^{\mathrm{o}}(x;\lambda)$ is defined as the *compound option* (i.e., the option value of the option value $L_k^{\mathrm{a}}(x;\lambda)$). We have $L_k^{\mathrm{o}}(x;\lambda)$ as

$$L_k^{\mathrm{o}}(x;\lambda) = \Big(\frac{x}{x_{\mathrm{L}k}^*}\Big)^{\beta}(L_k^{\mathrm{a}}(x_{\mathrm{L}k}^*;\lambda) - K_k), \tag{12}$$

where

$$x_{\mathrm{L}k}^* = \frac{\beta}{\beta-1}\frac{r-\mu}{D_1}K_k. \tag{13}$$

Note that $x_{\mathrm{L}k}^*$ does not depend on λ.

3 Strategic equilibrium

In this section, we provide the equilibrium for investment strategies. We then discuss some properties of the solution and value. Finally, we consider the effect of asymmetric access charge deregulation.

3.1 Investment strategies

We solve the firm's decision problem by working backwards using dynamic programming.

We first consider Firm k's problem as a follower after the rival firm (Firm k') enters the market. Firm k's optimization problem as a follower is choosing its investment timing strategy. We have already recognized two firms' optimal strategies. That is, the optimal strategies as a follower for the incumbent and entrant are to adopt the investment at x_{FI}^* and x_{FE}^*, respectively. Given these strategies, we then consider Firm k's problem as a leader.

[6] Similarly we have

$$L_k^{\mathrm{a}}(x;\lambda) = \frac{\lambda}{r+\lambda}L_k^{\mathrm{a}}(x;+\infty) + \big(1 - \frac{\lambda}{r+\lambda}\big)L_k^{\mathrm{a}}(x;0),$$

for any k ($k \in \{\mathrm{I},\mathrm{E}\}$).

To consider the optimal strategies as a leader for Firm k, it is important whether Firm k has an incentive to become a leader. If so, Firm k must consider the fact that Firm k' will aim to pre-empt it as soon as a certain trigger is reached. This trigger $x^*_{\mathrm{P}k}$ is the lowest realization of the process X_t, in which Firm k is indifferent between being the leader or the follower. Here, let the superscript "Pk" denote Firm k's *pre-emptive investment* strategy. Mathematically, $x^*_{\mathrm{P}k}$ is defined by

$$x^*_{\mathrm{P}k}(\lambda) := \inf\{x \geq 0; L^{\mathrm{a}}_k(x;\lambda) - K_k \geq F^{\mathrm{o}}_k(x;\lambda)\}, \tag{14}$$

for any k ($k \in \{\mathrm{I}, \mathrm{E}\}$). Importantly, $x^*_{\mathrm{P}k}(\lambda)$ does *not always* exist for any k ($k \in \{\mathrm{I}, \mathrm{E}\}$). Suppose, for example, $L^{\mathrm{a}}_k(x;\lambda) \leq F^{\mathrm{o}}_k(x;\lambda)$ for all values of x. Then $x^*_{\mathrm{P}k}(\lambda)$ does not exist. As a result, we show that there exists $x^*_{\mathrm{P}k}(\lambda) \in (0, x^*_{\mathrm{F}k}(\lambda))$ such that $L^{\mathrm{a}}_k(x;\lambda) \geq F^{\mathrm{o}}_k(x;\lambda)$ for some values of x ($x \in (0, x^*_{\mathrm{F}k})$). The proof is that value functions $L^{\mathrm{a}}_k(x;\lambda)$ and $F^{\mathrm{o}}_k(x;\lambda)$ are continuous with x, subject to $L^{\mathrm{a}}_k(0;\lambda) < 0 = F^{\mathrm{o}}_k(0;\lambda)$ for any k ($k \in \{\mathrm{I}, \mathrm{E}\}$).[7] This trigger $x^*_{\mathrm{P}k}(\lambda)$ is called the pre-emption triggers, at which Firm k is indifferent between the payoffs of acting as a leader or a follower. Here, it is straightforward to obtain the following result, because of the definition of pre-emption.

Lemma 1 *Suppose that there exists $x^*_{\mathrm{P}k}(\lambda)$ for any k ($k \in \{\mathrm{I}, \mathrm{E}\}$). Then, we have*

$$x^*_{\mathrm{P}k}(\lambda) < x^*_{\mathrm{L}k}(\lambda). \tag{15}$$

for any k ($k \in \{\mathrm{I}, \mathrm{E}\}$).

Now we consider strategic equilibrium with asymmetric cost technologies and asymmetric regulation between two firms. Strategic optimal strategies for leaders in equilibrium are attributed to the optimal strategies of followers.

The optimal investment strategies depend on the existence and the magnitude of the pre-emptive triggers. We summarize the results as follows.

Proposition 1 *Suppose there is a competitive market environment: we then have the following.*

(i) If there exists a unique trigger $x^*_{\mathrm{PE}}(\lambda)$ such that $x^*_{\mathrm{PE}}(\lambda) < x^*_{\mathrm{PI}}(\lambda)$, the entrant invests as a leader once the price process X_t starting at x arrives at $x^*_{\mathrm{PI}}(\lambda)$, the incumbent invests as a follower at $x^*_{\mathrm{FI}}(\lambda)$.

(ii) If there exist unique triggers $x^*_{\mathrm{PI}}(\lambda)$ and $x^*_{\mathrm{PE}}(\lambda)$ such that $x^*_{\mathrm{PI}}(\lambda) < x^*_{\mathrm{PE}}(\lambda) < x^*_{\mathrm{LI}}(\lambda)$, the incumbent invests as a leader at $x^*_{\mathrm{PE}}(\lambda)$, and the entrant invests as a follower at $x^*_{\mathrm{FE}}(\lambda)$.

[7] See Nishihara and Shibata (2010) for detail.

(iii) Otherwise, the incumbent invests as a leader at $x^*_{\mathrm{LI}}(\lambda)$, and the entrant invests as a follower at $x^*_{\mathrm{FE}}(\lambda)$.

Note that the entrant enters the market at $x^*_{\mathrm{PI}}(\lambda)$ not $x^*_{\mathrm{PE}}(\lambda)$ in case (i), and that the incumbent does so at $x^*_{\mathrm{PE}}(\lambda)$ not $x^*_{\mathrm{PI}}(\lambda)$ in case (ii). The reason is that we have $x^*_{\mathrm{PE}}(\lambda) < x^*_{\mathrm{PI}}(\lambda) < x^*_{\mathrm{LE}}(\lambda)$ in case (i). The reason in case (ii) follows in a similar manner.[8]

Most interestingly in Proposition 1, the entrant with the cost disadvantage has the possibility of adopting the new network as a leader under asymmetric access charge regulation. At first sight, this is surprising, but the result is caused by the benefit of a higher asymmetric access charge. These results correspond to the empirical findings in the Japanese cellular phone market. For example, the Japanese entrant KDDI corporation began providing a service based on the CDMA (Code Division Multiple Access) technology, which is known as "third generation (3G)" technology, earlier than the Japanese entrant NTT Docomo corporation.

3.2 Numerical implications

We confirm the empirical result with undertaking a concrete numerical analysis. We choose appropriate parameters to reflect the practice in the Japanese telecommunications industry. The parameters are $D_1 = 7$, $D_2 = 4$, $\sigma = 0.2$, $r = 0.09$, $\mu = 0.04$, $K_{\mathrm{I}} = 20$, $K_{\mathrm{E}} = 20.5$, $h = 2.5$, and $l = 2$. Most of these are similar to those used by Shibata and Yamazaki (2010). The additional parameter is deregulation intensity $\lambda = 0.05$. The choice of λ is necessarily arbitrary, so we simply set it equal to the frequency of deregulation in Japanese telecommunications.

Figure 1 illustrates the value functions with respect to the state variable. The left and right panels of Figure 1 depict the leader's and the follower's value functions for the incumbent and the entrant, respectively. The investment triggers for the incumbent and the entrant in Figure 1 are summarized in Table 2. Under the above parameters, there exist the pre-emption triggers x^*_{PI} and x^*_{PE} such that $x^*_{\mathrm{PE}} < x^*_{\mathrm{PI}}$. The entrant has an incentive to invest as a leader when $x \geq x^*_{\mathrm{PE}} = 0.2371$ and recognizes that the entrant does not enter the market when $x < x^*_{\mathrm{PI}} = 0.2802$. Thus, the entrant invests as a leader at x^*_{PI}, *not* x^*_{PE}.[9] As a result, at equilibrium, the entrant with a cost disadvantage enters the new market as a leader at $x^*_{\mathrm{PI}} = 0.2802$ while the incumbent with a cost advantage enters the market as a follower at $x^*_{\mathrm{FI}} = 0.7283$. That is, an asymmetric access charge regulation may lead the entrant to enter the new market as a leader even under the potential threat

[8]We consider the equilibrium in detail using the numerical example in Figure 1.

[9]This situation is the same as in Pawlina and Kort (2006) and Kong and Kwok (2007).

of the removal of asymmetric regulation.

[Insert Figure 1 about here]

[Insert Table 2 about here]

3.3 Asymmetric access charge and welfare analysis

In this section, we consider the effect of asymmetric access charge on the investment strategy and welfare. We begin with the definition of the welfare measure. We then analyse the effect of asymmetric access charge on investment and welfare.

3.3.1 Definition of welfare measure

In the economics literature, the measure of efficiency in welfare called the "total surplus", is defined as the sum of the "consumer surplus" and "producer surplus." and is a standard concept in the microeconomics literature (see, e.g., Mas-Colell et al. (1995)). First, we begin by deriving the consumer surplus. It is natural that the consumer surplus is a multiplicative function of x and that it is positively affected by firm investments. We denote the instantaneous consumer surplus in monopoly and duopoly by $S_1 x$ and $S_2 x$, respectively. We assume that $S_2 > S_1 > 0$. This implies that the coefficient of the instantaneous consumer surplus is larger in the monopoly than in the duopoly. This assumption is intuitively reasonable. There are two network facilities in a duopoly while there is only one network facility in a monopoly. The consumer surplus, $CS(x;\lambda)$, is defined as

$$CS(x;\lambda) := \mathbb{E}^x \Big[\int_{\tau^*_{hk}}^{\tau^*_{\mathrm{F}k'}} \mathrm{e}^{-ru} S_1 X_u \mathrm{d}u + \int_{\tau^*_{\mathrm{F}k'}}^{+\infty} \mathrm{e}^{-ru} S_2 X_u \mathrm{d}u \Big],$$

for any k, k', and h $(k, k' \in \{\mathrm{I}, \mathrm{E}\}, k \neq k', h \in \{\mathrm{P}, \mathrm{L}\})$. Similar to the derivation of (2), we have

$$CS(x;\lambda) = \frac{S_1 x^*_{hk}}{r-\mu}\Big(\frac{x}{x^*_{hk}}\Big)^{\beta} + \frac{(S_2 - S_1) x^*_{\mathrm{F}k'}}{r-\mu}\Big(\frac{x}{x^*_{\mathrm{F}k'}}\Big)^{\beta}. \tag{16}$$

Hereafter we write $CS(x;\lambda)$ as $CS(x; x^*_{hk}(\lambda), x^*_{\mathrm{F}k'}(\lambda))$. Second, we consider the producer surplus defined by the sum of the incumbent's and the entrant's values, $I(x;\lambda)$ and $E(x;\lambda)$. That is, the producer surplus $PS(x;\lambda)$ is

$$PS(x;\lambda) := I(x;\lambda) + E(x;\lambda). \tag{17}$$

Finally, the total surplus is defined by the sum of the consumer and producer surpluses: i.e.,

$$TS(x;\lambda) := CS(x;\lambda) + PS(x;\lambda). \tag{18}$$

These definitions are the same as in Pawlina and Kort (2006) and Shibata and Yamazaki (2010).

3.3.2 Optimal investment strategies

To analyse the welfare analysis with asymmetric access charge regulation, we begin by deriving the investment triggers and values with asymmetric access charge regulation at the equilibrium. Here, the access charge h is changed from 2.00 to 3.00 for fixed l ($l = 2.0$). Note that the access charge regulation is *symmetric* if $h = 2.00$, and *asymmetric* otherwise. The other parameters are exactly the same as in the previous subsection.[10]

Figure 2 demonstrates the investment trigger with asymmetric access charge h. The upper left-hand panel depicts the investment triggers as a leader. For $h \in [2.00, 2.62)$, there exists x^*_{PI}, which is increasing and convex with h. For all $h \in [2.00, 3.00]$, there exists x^*_{PE} which has a U-shaped curve with h. We have $x^*_{\mathrm{PI}} < x^*_{\mathrm{PE}}$ for $h < 2.14$ and $x^*_{\mathrm{PE}} < x^*_{\mathrm{PI}}$ for $2.14 < h < 2.62$. Consequently, we derive the investment strategies of a leader at the equilibrium. For $h \in [2.00, 2.14)$, the incumbent invests as a leader at x^*_{PE} because $x^*_{\mathrm{PI}} < x^*_{\mathrm{PE}} < x^*_{\mathrm{LI}}$. For $h = 2.14$, each firm invests as a leader at $x^*_{\mathrm{PI}} = x^*_{\mathrm{PE}}$ with probability one half.[11] For $h \in (2.14, 2.62)$, the entrant invests as a leader at x^*_{PI} because of $x^*_{\mathrm{PE}} < x^*_{\mathrm{PI}} < x^*_{\mathrm{LE}}$. For $h \geq 2.62$, the entrant invests as a leader at x^*_{LI}. The investment trigger of a leader at the equilibrium is described by the bold blue dotted line. We can see that at the equilibrium the pre-emptive trigger is lowest at $h = 2.14$. This is because it is decreasing when $h < 2.14$, but it is increasing when $h > 2.14$.

[Insert Figure 2 about here]

The upper right-hand panel of Figure 2 shows the investment triggers of a follower. We can see that x^*_{FI} and x^*_{FE} are increasing and decreasing in h, respectively. Given the optimal investment trigger of a leader, we derive the optimal investment trigger of a follower. At the equilibrium, the entrant invests as a follower at x^*_{FE} for $h < 2.14$, the

[10] That is, $D_1 = 7$, $D_2 = 4$, $\sigma = 0.2$, $r = 0.09$, $\mu = 0.04$, $K_{\mathrm{I}} = 20$, $K_{\mathrm{E}} = 20.5$, and $\lambda = 0.05$.

[11] For $h = 2.14$, to be more precise, two firms (i.e., Firms I and E) have an incentive to enter the market as leaders at $x^*_{\mathrm{FI}} = x^*_{\mathrm{FE}}$. Because the two firms are then completely *symmetric* under asymmetric regulation, each firm enters the market with probability one half. This finding is the same as in Nishihara and Shibata (2010).

incumbent and the entrant invest as followers with probability one half at respective x^*_{FI} and x^*_{FE} for $h = 2.14$, and the incumbent invests as a follower at x^*_{FI} for $h > 2.14$.

To summarize the upper left and right panels, the investment trigger of a leader and follower are lowest at $h = 2.14$, where the competitive market environment between the incumbent and the entrant is completely *symmetric*. Thus, moderate asymmetric access charge regulation accelerates the investment. To stimulate the competition, it is preferable for the policy maker to set a moderate asymmetric access charge. We show that the extremes of small and large asymmetric access charges should not be applied.

3.3.3 Optimal values

Next, given the firms' optimal strategies, the incumbent's and entrant's values, $I(x;\lambda)$ and $E(x;\lambda)$, are

$$I(x;\lambda) = \begin{cases} \left(\frac{x}{x^*_{\mathrm{PE}}(\lambda)}\right)^{\beta}(L^{\mathrm{a}}_{\mathrm{I}}(x^*_{\mathrm{PE}}(\lambda);\lambda) - K_{\mathrm{I}}), & \text{if } h \in [2.00, 2.14), \\ \frac{1}{2}\left(\frac{x}{x^*_{\mathrm{PE}}(\lambda)}\right)^{\beta}(L^{\mathrm{a}}_{\mathrm{I}}(x^*_{\mathrm{PE}}(\lambda);\lambda) - K_{\mathrm{I}}) + \frac{1}{2}\left(\frac{x}{x^*_{\mathrm{FI}}(\lambda)}\right)^{\beta}(F^{\mathrm{a}}_{\mathrm{I}}(x^*_{\mathrm{FI}}(\lambda);\lambda) - K_{\mathrm{I}}), & \text{if } h = 2.14, \\ \left(\frac{x}{x^*_{\mathrm{FI}}(\lambda)}\right)^{\beta}(F^{\mathrm{a}}_{\mathrm{I}}(x^*_{\mathrm{FI}}(\lambda);\lambda) - K_{\mathrm{I}}), & \text{otherwise}, \end{cases} \tag{19}$$

and

$$E(x;\lambda) = \begin{cases} \left(\frac{x}{x^*_{\mathrm{FE}}(\lambda)}\right)^{\beta}(F^{\mathrm{a}}_{\mathrm{E}}(x^*_{\mathrm{FE}}(\lambda);\lambda) - K_{\mathrm{E}}), & \text{if } h \in [2.00, 2.14), \\ \frac{1}{2}\left(\frac{x}{x^*_{\mathrm{PI}}(\lambda)}\right)^{\beta}(L^{\mathrm{a}}_{\mathrm{E}}(x^*_{\mathrm{PI}}(\lambda);\lambda) - K_{\mathrm{E}}) + \frac{1}{2}\left(\frac{x}{x^*_{\mathrm{FE}}(\lambda)}\right)^{\beta}(F^{\mathrm{a}}_{\mathrm{E}}(x^*_{\mathrm{FE}}(\lambda);\lambda) - K_{\mathrm{E}}), & \text{if } h = 2.14, \\ \left(\frac{x}{x^*_{\mathrm{PI}}(\lambda)}\right)^{\beta}(L^{\mathrm{a}}_{\mathrm{E}}(x^*_{\mathrm{PI}}(\lambda);\lambda) - K_{\mathrm{E}}), & \text{if } h \in (2.14, 2.62), \\ \left(\frac{x}{x^*_{\mathrm{LI}}(\lambda)}\right)^{\beta}(L^{\mathrm{a}}_{\mathrm{E}}(x^*_{\mathrm{LI}}(\lambda);\lambda) - K_{\mathrm{E}}), & \text{otherwise}. \end{cases} \tag{20}$$

The middle left-hand panel of Figure 2 depicts the incumbent's and the entrant's values with respect to h. We see that the incumbent's value is monotonically decreasing in h while the entrant's value is monotonically increasing in h. Thus, an increase in h shifts wealth from the incumbent to the entrant. This possibility of transferring wealth is known as "asset substitution" from the incumbent to the entrant via asymmetric access charge regulation. In addition, there is a turning point at $h = 2.14$ where the strategies of the incumbent and the entrant as leader and follower, respectively, interchange. At $h = 2.14$, the entrant's value jumps upward.

3.3.4 Welfare

We consider welfare analysis with respect to asymmetric access charge h. Here, we suppose $S_1 = 50$ and $S_2 = 80$. The other parameters are the same as in the previous subsection.

Under these parameters, the consumer and producer surpluses are

$$CS(x;\lambda) = \begin{cases} CS(x; x^*_{\mathrm{PE}}(\lambda), x^*_{\mathrm{FE}}(\lambda)), & \text{if } h \in [2.00, 2.14), \\ CS(x; x^*_{\mathrm{PE}}(\lambda), \frac{1}{2}x^*_{\mathrm{FI}}(\lambda) + \frac{1}{2}x^*_{\mathrm{FE}}(\lambda)), & \text{if } h = 2.14, \\ CS(x; x^*_{\mathrm{PI}}(\lambda), x^*_{\mathrm{FI}}(\lambda)), & \text{if } h \in (2.14, 2.66), \\ CS(x; x^*_{\mathrm{LI}}(\lambda), x^*_{\mathrm{FI}}(\lambda)), & \text{otherwise}, \end{cases} \tag{21}$$

and

$$\begin{aligned} &PS(x;\lambda) \\ &= \begin{cases} \left(\frac{x}{x^*_{\mathrm{PE}}(\lambda)}\right)^\beta (L^{\mathrm{a}}_{\mathrm{I}}(x^*_{\mathrm{PE}}(\lambda);\lambda) - K_{\mathrm{I}}) + \left(\frac{x}{x^*_{\mathrm{FE}}(\lambda)}\right)^\beta (F^{\mathrm{a}}_{\mathrm{E}}(x^*_{\mathrm{FE}}(\lambda);\lambda) - K_{\mathrm{E}}), & \text{if } h \in [2.00, 2.14), \\ \frac{1}{2}\left(\frac{x}{x^*_{\mathrm{PE}}(\lambda)}\right)^\beta (L^{\mathrm{a}}_{\mathrm{I}}(x^*_{\mathrm{PE}}(\lambda);\lambda) - K_{\mathrm{I}}) + \frac{1}{2}\left(\frac{x}{x^*_{\mathrm{FI}}(\lambda)}\right)^\beta (F^{\mathrm{a}}_{\mathrm{I}}(x^*_{\mathrm{FI}}(\lambda);\lambda) - K_{\mathrm{I}}) & \\ +\frac{1}{2}\left(\frac{x}{x^*_{\mathrm{PI}}(\lambda)}\right)^\beta (L^{\mathrm{a}}_{\mathrm{E}}(x^*_{\mathrm{PI}}(\lambda);\lambda) - K_{\mathrm{E}}) + \frac{1}{2}\left(\frac{x}{x^*_{\mathrm{FE}}(\lambda)}\right)^\beta (F^{\mathrm{a}}_{\mathrm{E}}(x^*_{\mathrm{FE}}(\lambda);\lambda) - K_{\mathrm{E}}), & \text{if } h = 2.14, \\ \left(\frac{x}{x^*_{\mathrm{FI}}(\lambda)}\right)^\beta (F^{\mathrm{a}}_{\mathrm{I}}(x^*_{\mathrm{FI}}(\lambda);\lambda) - K_{\mathrm{I}}) + \left(\frac{x}{x^*_{\mathrm{PI}}(\lambda)}\right)^\beta (L^{\mathrm{a}}_{\mathrm{E}}(x^*_{\mathrm{PI}}(\lambda);\lambda) - K_{\mathrm{E}}), & \text{if } h \in (2.14, 2.62), \\ \left(\frac{x}{x^*_{\mathrm{FI}}(\lambda)}\right)^\beta (F^{\mathrm{a}}_{\mathrm{I}}(x^*_{\mathrm{FI}}(\lambda);\lambda) - K_{\mathrm{I}}) + \left(\frac{x}{x^*_{\mathrm{LI}}(\lambda)}\right)^\beta (L^{\mathrm{a}}_{\mathrm{E}}(x^*_{\mathrm{LI}}(\lambda);\lambda) - K_{\mathrm{E}}), & \text{otherwise.} \end{cases} \end{aligned} \tag{22}$$

The middle right-hand panel of Figure 2 depicts the consumer and producer surpluses with respect to h. Interestingly, the consumer surplus is increasing and decreasing in h for $h < 2.14$ and $h > 2.14$, respectively. In contrast, the producer surplus is decreasing and increasing in h for $h < 2.14$ and $h > 2.14$, respectively. As a result, the consumer and producer surpluses are highest and lowest, respectively, at $h = 2.14$, where the competitive environment between two firms is completely symmetric. We recognize that there are trade-offs of efficiencies between the consumer surplus and producer surplus. These results are consistent with the findings of previous theoretical and empirical works.

The lower left-hand panel of Figure 2 demonstrates the total surplus. The total surplus is increasing when $h \leq 2.14$, while it is non-monotonic when $h > 2.14$. The total surplus is highest when the two firms are completely symmetric. This result corresponds with the findings of theoretical studies.

4 Deregulation uncertainty

In this section, we analyse the effects of the more important parameter, deregulation intensity. Here, the deregulation intensity parameter λ is changed from 0.00 to 0.80. The other parameters are exactly the same as in the previous subsection.

4.1 Optimal investment triggers

The top left- and right-hand panels of Figure 3 depict the investment triggers of a leader and a follower, respectively. In the top left-hand panel, there are two important properties. The first property is the existence and the shape of the pre-emptive investment triggers. There exist incumbent's and entrant's pre-emptive investment triggers x^*_{PI} and x^*_{PE} for all λ ($\lambda \in (0, 0.8)$). The incumbent's pre-emptive trigger x^*_{PI} is decreasing in λ, while the entrant's pre-emptive trigger x^*_{PI} is increasing in λ. The second property is the magnitude of the pre-emptive investment triggers. We have $x^*_{\mathrm{PI}} > x^*_{\mathrm{PE}}$ for $\lambda < 0.41$ while $x^*_{\mathrm{PI}} < x^*_{\mathrm{PE}}$ for $\lambda > 0.41$. Thus, we obtain $x^*_{\mathrm{PI}} = x^*_{\mathrm{PE}}$ for $\lambda = 0.41$. Consequently, for $\lambda \leq 0.41$, the entrant invests as a leader at x^*_{PI} because $x^*_{\mathrm{PE}} < x^*_{\mathrm{PI}} < x^*_{\mathrm{LE}}$. For $\lambda = 0.41$, each firm invests as a leader at $x^*_{\mathrm{PI}} = x^*_{\mathrm{PE}}$ with probability one half.[12] For $\lambda > 0.41$, the incumbent invests as a leader at x^*_{PE} because of $x^*_{\mathrm{PI}} < x^*_{\mathrm{PE}} < x^*_{\mathrm{LE}}$. The pre-emptive investment trigger at the equilibrium, shown by the bold blue dotted line, has a U-shaped curve with deregulation intensity λ.

[Insert Figure 3 about here]

In the top right-hand panel, we can see that x^*_{FI} and x^*_{FE} are decreasing and increasing in h, respectively. For $\lambda < 0.41$, at the equilibrium, the incumbent adopts a new network facility as a follower at x^*_{FI}. For $\lambda = 0.41$, each firm does so at $x^*_{\mathrm{FI}} = x^*_{\mathrm{FE}}$ with probability one half. For $\lambda > 0.41$, the entrant does so at x^*_{FE}.

In summary, the investment trigger is lowest at $\lambda = 0.41$, where the competitive market environment between the incumbent and the entrant is completely *symmetric*. We conclude that moderate deregulation intensity accelerates investment (decreases the investment triggers). To stimulate investment, it is preferable for a policy maker to set a moderate level of deregulation intensity.

4.2 Optimal values

Given the firms' optimal strategies, the incumbent's and entrant's values, $I(x)$ and $E(x)$, are

$I(x; \lambda)$

[12]The assumption of the outcome for $\lambda = 0.41$ is exactly the same as that for $h = 2.14$ in the previous subsection.

$$
= \begin{cases} \left(\frac{x}{x^*_{\mathrm{FI}}(\lambda)}\right)^{\beta}(F^{\mathrm{a}}_{\mathrm{I}}(x^*_{\mathrm{FI}}(\lambda);\lambda)-K_{\mathrm{I}}), & \text{if } \lambda\in[0,0.41),\\ \frac{1}{2}\left(\frac{x}{x^*_{\mathrm{PE}}(\lambda)}\right)^{\beta}(L^{\mathrm{a}}_{\mathrm{I}}(x^*_{\mathrm{PE}}(\lambda);\lambda)-K_{\mathrm{I}})+\frac{1}{2}\left(\frac{x}{x^*_{\mathrm{FI}}(\lambda)}\right)^{\beta}(F^{\mathrm{a}}_{\mathrm{I}}(x^*_{\mathrm{FI}}(\lambda);\lambda)-K_{\mathrm{I}}), & \text{if } \lambda=0.41,\\ \left(\frac{x}{x^*_{\mathrm{PE}}(\lambda)}\right)^{\beta}(L^{\mathrm{a}}_{\mathrm{I}}(x^*_{\mathrm{PE}}(\lambda);\lambda)-K_{\mathrm{I}}), & \text{otherwise,} \end{cases} \tag{23}
$$

and

$$
E(x;\lambda)
$$

$$
= \begin{cases} \left(\frac{x}{x^*_{\mathrm{PI}}(\lambda)}\right)^{\beta}(L^{\mathrm{a}}_{\mathrm{E}}(x^*_{\mathrm{PI}}(\lambda);\lambda)-K_{\mathrm{E}}), & \text{if } \lambda\in[0,0.41),\\ \frac{1}{2}\left(\frac{x}{x^*_{\mathrm{PI}}(\lambda)}\right)^{\beta}(L^{\mathrm{a}}_{\mathrm{E}}(x^*_{\mathrm{PI}}(\lambda);\lambda)-K_{\mathrm{E}})+\frac{1}{2}\left(\frac{x}{x^*_{\mathrm{FE}}(\lambda)}\right)^{\beta}(F^{\mathrm{a}}_{\mathrm{E}}(x^*_{\mathrm{FE}}(\lambda);\lambda)-K_{\mathrm{E}}), & \text{if } \lambda=0.41,\\ \left(\frac{x}{x^*_{\mathrm{FE}}(\lambda)}\right)^{\beta}(F^{\mathrm{a}}_{\mathrm{E}}(x^*_{\mathrm{FE}}(\lambda);\lambda)-K_{\mathrm{E}}), & \text{otherwise,} \end{cases} \tag{24}
$$

The middle left-hand panel of Figure 3 illustrates the incumbent's and the entrant's values with respect to λ. Naturally, the incumbent's value is monotonically increasing in λ while the entrant's value is monotonically decreasing in λ. An increase in λ shifts wealth from the entrant to the incumbent. At $\lambda = 0.41$, there is a turning point where the strategies of the incumbent and the entrant as leader and follower, respectively, interchange. Moreover, at $\lambda = 0.68$, there is a turning point where the incumbent's and entrant's values interchange.

4.3 Welfare

We consider efficiency in welfare with respect to λ. The consumer and producer surpluses, $CS(x;\lambda)$ and $PS(x;\lambda)$, are

$$
CS(x;\lambda) = \begin{cases} CS(x;x^*_{\mathrm{PI}}(\lambda),x^*_{\mathrm{FI}}(\lambda)), & \text{if } \lambda\in[0,0.41),\\ CS(x;x^*_{\mathrm{PE}}(\lambda),\tfrac{1}{2}x^*_{\mathrm{FI}}(\lambda)+\tfrac{1}{2}x^*_{\mathrm{FE}}(\lambda)), & \text{if } \lambda=0.41,\\ CS(x;x^*_{\mathrm{PE}}(\lambda),x^*_{\mathrm{FE}}(\lambda)), & \text{otherwise,} \end{cases} \tag{25}
$$

and

$$
PS(x;\lambda)
$$

$$
= \begin{cases} \left(\frac{x}{x^*_{\mathrm{FI}}(\lambda)}\right)^{\beta}(F^{\mathrm{a}}_{\mathrm{I}}(x^*_{\mathrm{FI}}(\lambda);\lambda)-K_{\mathrm{I}})+\left(\frac{x}{x^*_{\mathrm{PI}}(\lambda)}\right)^{\beta}(L^{\mathrm{a}}_{\mathrm{E}}(x^*_{\mathrm{PI}}(\lambda);\lambda)-K_{\mathrm{E}}), & \text{if } \lambda\in[0,0.41),\\ \frac{1}{2}\left(\frac{x}{x^*_{\mathrm{PE}}(\lambda)}\right)^{\beta}(L^{\mathrm{a}}_{\mathrm{I}}(x^*_{\mathrm{PE}}(\lambda);\lambda)-K_{\mathrm{I}})+\frac{1}{2}\left(\frac{x}{x^*_{\mathrm{FI}}(\lambda)}\right)^{\beta}(F^{\mathrm{a}}_{\mathrm{I}}(x^*_{\mathrm{FI}}(\lambda);\lambda)-K_{\mathrm{I}}) & \\ +\frac{1}{2}\left(\frac{x}{x^*_{\mathrm{PI}}(\lambda)}\right)^{\beta}(L^{\mathrm{a}}_{\mathrm{E}}(x^*_{\mathrm{PI}}(\lambda);\lambda)-K_{\mathrm{E}})+\frac{1}{2}\left(\frac{x}{x^*_{\mathrm{FE}}(\lambda)}\right)^{\beta}(F^{\mathrm{a}}_{\mathrm{E}}(x^*_{\mathrm{FE}}(\lambda);\lambda)-K_{\mathrm{E}}), & \text{if } \lambda=0.41,\\ \left(\frac{x}{x^*_{\mathrm{PE}}(\lambda)}\right)^{\beta}(L^{\mathrm{a}}_{\mathrm{I}}(x^*_{\mathrm{PE}}(\lambda);\lambda)-K_{\mathrm{I}})+\left(\frac{x}{x^*_{\mathrm{FE}}(\lambda)}\right)^{\beta}(F^{\mathrm{a}}_{\mathrm{E}}(x^*_{\mathrm{FE}}(\lambda);\lambda)-K_{\mathrm{E}}), & \text{otherwise.} \end{cases} \tag{26}
$$

The middle right-hand panel of Figure 3 shows the consumer and producer surpluses with respect to λ. The consumer surplus is increasing and decreasing in λ when $\lambda < 0.41$ and $\lambda > 0.41$, respectively. On the other hand, the producer surplus is decreasing and increasing in λ when $\lambda < 0.41$ and $\lambda > 0.41$, respectively. We conclude that the consumer and producer surpluses are respectively highest and lowest at $\lambda = 0.41$, where the competitive environment between two firms is completely symmetric. This finding, that the consumer and producer surpluses are highest and lowest, respectively, when the two firms are completely symmetric, is robust in our model.

The bottom left-hand panel demonstrates the total surplus with λ. The total surplus is non-monotonic with λ.

5 Asymmetric deregulation uncertainty

So far, we have assumed that both the incumbent and the entrant have the same deregulation intensity. However, deregulation intensity may differ between firms. A potential justification exists for such an assumption. For example, two firms may have different outlooks in terms of being optimistic or pessimistic about the prospect of deregulation (termination of an asymmetric access charge regulation). That is, two firms may differ in their impatience for deregulation. This idea is similar to that in Nishihara and Fukushima (2008).

In this section, we assume that the incumbent's deregulation intensity λ_{I} is different from that of the entrant λ_{E}. More precisely, the incumbent and the entrant believe that the timing follows an exponential distribution with λ_{I} and λ_{E}, respectively. We consider the effects of asymmetric deregulation intensity on investment strategies and welfare using the numerical examples.

5.1 Strategic equilibrium

Under asymmetric deregulation intensity, the value functions of a leader and a follower, $L_k^{\mathrm{a}}(x;\lambda_{\mathrm{I}},\lambda_{\mathrm{E}})$ and $F_k^{\mathrm{o}}(x;\lambda_k)$, are defined as

$$L_k^{\mathrm{a}}(x;\lambda_{\mathrm{I}},\lambda_{\mathrm{E}}) = \frac{D_1}{r-\mu}x + \Big(\frac{x}{x_{\mathrm{F}k'}^*(\lambda_{k'})}\Big)^\beta \Big(\frac{D_2-D_1}{r-\mu}x_{\mathrm{F}k'}^*(\lambda_{k'}) + \frac{v_k - v_{k'}}{r+\lambda_k}\Big) \quad (27)$$

$$F_k^{\mathrm{o}}(x;\lambda_k) = \Big(\frac{x}{x_{\mathrm{F}k}^*}\Big)^\beta \Big(\frac{D_2}{r-\mu}x + \frac{v_k - v_{k'}}{r+\lambda_k} - K_k\Big), \quad (28)$$

for any k and k' $(k,k' \in \{\mathrm{I},\mathrm{E}\})$. Based on these values, we derive the pre-emptive investment trigger under asymmetric deregulation uncertainty as follows:

$$x_{\mathrm{P}k}^*(\lambda_{\mathrm{I}},\lambda_{\mathrm{E}}) := \inf\{x \geq 0; L_k^{\mathrm{a}}(x;\lambda_{\mathrm{I}},\lambda_{\mathrm{E}}) - K_k \geq F_k^{\mathrm{o}}(x;\lambda_k)\}, \quad (29)$$

for any k ($k \in \{\mathrm{I}, \mathrm{E}\}$). Note that Firm k's pre-emptive trigger $x^*_{\mathrm{P}k}(\lambda_\mathrm{I}, \lambda_\mathrm{E})$ depends on λ_I and λ_E. Similarly in the symmetric deregulation uncertainty case, we have the following result.

Corollary 1 *Under asymmetric deregulation uncertainty, Firm k enters the market as a leader if $x^*_{\mathrm{P}k}(\lambda_\mathrm{I}, \lambda_\mathrm{E}) < x^*_{\mathrm{P}k'}(\lambda_\mathrm{I}, \lambda_\mathrm{E})$ for any k ($k, k' \in \{\mathrm{I}, \mathrm{E}\}$, $k \neq k'$). Then, at the equilibrium, Firm k invests as a leader at $x^*_{\mathrm{P}k'}(\lambda_\mathrm{I}, \lambda_\mathrm{E})$ and Firm k' invests as a follower at $x^*_{\mathrm{F}k'}(\lambda_{k'})$.*

The proof is exactly the same as in the symmetric deregulation uncertainty case. The values of a leader and follower are obtained by incorporating, the respective investment triggers into value functions.

Finally, to consider welfare efficiency with respect to asymmetric deregulation uncertainty, we define the total surplus $TS(x; \lambda_\mathrm{I}, \lambda_\mathrm{E})$ as

$$TS(x; \lambda_\mathrm{I}, \lambda_\mathrm{E}) := CS(x; \lambda_\mathrm{I}, \lambda_\mathrm{E}) + PS(x; \lambda_\mathrm{I}, \lambda_\mathrm{E}) \tag{30}$$

where

$$CS(x; \lambda_\mathrm{I}, \lambda_\mathrm{E}) := \frac{S_1 x^*_{hk}(\lambda_\mathrm{I}, \lambda_\mathrm{E})}{r-\mu}\Big(\frac{x}{x^*_{hk}(\lambda_\mathrm{I}, \lambda_\mathrm{E})}\Big)^\beta + \frac{(S_2 - S_1) x^*_{\mathrm{F}k'}(\lambda_{k'})}{r-\mu}\Big(\frac{x}{x^*_{\mathrm{F}k'}(\lambda_{k'})}\Big)^\beta \tag{31}$$

$$PS(x; \lambda_\mathrm{I}, \lambda_\mathrm{E}) := I(x; \lambda_\mathrm{I}, \lambda_\mathrm{E}) + E(x; \lambda_\mathrm{I}, \lambda_\mathrm{E}). \tag{32}$$

These definitions are the same as those in the symmetric deregulation uncertainty case.

5.2 Incumbent's misunderstanding

In this subsection, we consider the effect of λ_I for a fixed $\lambda_\mathrm{E} = \lambda = 0.05$. Recall that, as a benchmark, under a symmetric access charge, $\lambda_\mathrm{I} = \lambda_\mathrm{E} = \lambda = 0.05$, the entrant invests as a leader. In this subsection, we assume that λ_I is changed from 0.05 to 0.8 for a fixed $\lambda_\mathrm{E} = \lambda = 0.05$. This parameter shift is regarded as the scenario that only the incumbent misunderstands λ_I as $\lambda_\mathrm{I} \neq \lambda$.

We now consider the investment strategy. The upper left- and right-hand side panels of Figure 4 depict the investment triggers of a leader and a follower, respectively. In the left-hand side panel, $x^*_{\mathrm{PI}}(\lambda_\mathrm{I}, \lambda)$ is larger than $x^*_{\mathrm{PE}}(\lambda_\mathrm{I}, \lambda)$ for all regions $\lambda_\mathrm{I} \in [0.05, 0.80]$. Thus, the entrant is a leader in all regions. At the equilibrium, the entrant invests as a leader at $x^*_{\mathrm{PI}}(\lambda_\mathrm{I}, \lambda)$, the incumbent invests as a follower at $x^*_{\mathrm{FI}}(\lambda_\mathrm{I})$. Here, the leader's and follower's investment triggers, $x^*_{\mathrm{PI}}(\lambda_\mathrm{I}, \lambda)$ and $x^*_{\mathrm{FI}}(\lambda_\mathrm{I})$ for $\lambda_\mathrm{I} > \lambda$, are smaller than those for $\lambda_\mathrm{I} = \lambda$. Thus, the incumbent's misunderstanding of λ_I as $\lambda_\mathrm{I} \neq \lambda$ leads to a decrease in the investment triggers of leader and follower. The dashed line depicts the investment trigger at the equilibrium under asymmetric deregulation intensity (the dotted line shows the trigger under symmetric deregulation intensity as explained in the previous section). We can see that the leader's and the follower's investment triggers under asymmetric intensity are larger at the equilibrium larger than those under symmetric intensity.

The lower panel of Figure 4 shows the consumer and producer surpluses. Because the investment triggers of leader and follower are decreasing with λ_{E}, the consumer surplus $CS(x; \lambda_{\mathrm{I}}, \lambda)$ is also increasing with λ_{I}. The producer surplus $PS(x; \lambda_{\mathrm{I}}, \lambda)$ is decreasing with λ_{I} by misunderstanding λ_{I} as $\lambda_{\mathrm{I}} \neq \lambda$. Thus, $CS(x; \lambda_{\mathrm{I}}, \lambda)$ and $PS(x; \lambda_{\mathrm{I}}, \lambda)$, are increasing and decreasing with λ_{I}, respectively. $CS(x; \lambda_{\mathrm{I}}, \lambda)$ and $PS(x; \lambda_{\mathrm{I}}, \lambda)$ for $\lambda_{\mathrm{I}} > \lambda = 0.05$ are larger and smaller than those for $\lambda_{\mathrm{I}} = \lambda = 0.05$, respectively. The increase in the consumer surplus is larger than the decrease in the producer surplus. Thus, the total surplus $TS(x; \lambda_{\mathrm{I}}, \lambda)$ is increasing with λ_{I}, as shown in the lower right-hand side panel. Interestingly, when the incumbent mistakes λ_{I} for $\lambda_{\mathrm{I}} \neq \lambda$, the total surplus for $\lambda_{\mathrm{I}} > \lambda$ is larger than the one for $\lambda_{\mathrm{I}} = \lambda$. This implies that the misunderstanding leads to the increase in the total surplus.

[Insert Figure 4 about here]

5.3 Entrant's misunderstanding

In this subsection, in contrast to that above, we consider the effect of λ_{E} for a fixed $\lambda_{\mathrm{I}} = \lambda = 0.05$. Therefore, we assume that λ_{E} is changed from 0.05 to 0.8 for a fixed $\lambda_{\mathrm{I}} = \lambda = 0.05$. This parameter shift is regarded as the scenario that only the entrant mistakes λ_{E} for $\lambda_{\mathrm{E}} \neq \lambda$.

We consider the investment strategy. The upper left-hand and right-hand side panels of Figure 5 depict the investment triggers of a leader and a follower, respectively. In the left-hand side panel, $x^*_{\mathrm{PI}}(\lambda, \lambda_{\mathrm{E}})$ is larger than $x^*_{\mathrm{PE}}(\lambda, \lambda_{\mathrm{E}})$ for all the regions $\lambda_{\mathrm{E}} \in [0.05, 0.80]$. Thus, the entrant become a leader for all regions. At the equilibrium, the entrant enters the market as a leader at $x^*_{\mathrm{PI}}(\lambda, \lambda_{\mathrm{E}})$, the incumbent does the market as a follower at $x^*_{\mathrm{FI}}(\lambda)$. Here, the leader's investment trigger $x^*_{\mathrm{PI}}(\lambda, \lambda_{\mathrm{E}})$ is decreasing with λ_{E} as shown in the upper left-hand side panel, while the follower's investment trigger x^*_{FI} is constant with λ_{E} as shown in the right-hand side panel. The dashed line depicts the investment trigger at the equilibrium under asymmetric deregulation intensity (the dotted line does the trigger under symmetric deregulation intensity as explained in the previous section). We see that the leader's and the follower's investment triggers under asymmetric intensity are at the equilibrium smaller and larger than those under symmetric intensity, respectively.

The lower panel of Figure 5 shows the consumer and producer surpluses with respect to λ_{E}. In the lower left-hand side panel, the consumer and producer surpluses, $CS(x;\lambda,\lambda_{\mathrm{E}})$ and $PS(x;\lambda,\lambda_{\mathrm{E}})$, are increasing and decreasing with λ_{E}, respectively. In other words, $CS(x;\lambda,\lambda_{\mathrm{E}})$ and $PS(x;\lambda,\lambda_{\mathrm{E}})$ for $\lambda_{\mathrm{E}} > \lambda = 0.05$ are larger and smaller than those for $\lambda_{\mathrm{E}} = \lambda = 0.05$. The increase in $CS(x;\lambda,\lambda_{\mathrm{E}})$ for $\lambda_{\mathrm{E}} \neq \lambda$ is smaller than the decrease in $PS(x;\lambda,\lambda_{\mathrm{E}})$ for $\lambda_{\mathrm{E}} \neq \lambda$. Thus, the total surplus $TS(x;\lambda,\lambda_{\mathrm{E}})$ is decreasing with λ_{E} for $\lambda_{\mathrm{E}} > \lambda = 0.05$ in the lower right-hand side panel. When the entrant mistakes λ_{E} for $\lambda_{\mathrm{E}} \neq \lambda$, the total surplus for $\lambda_{\mathrm{E}} > \lambda$ is smaller than that for $\lambda_{\mathrm{E}} = \lambda$.

[Insert Figure 5 about here]

6 Concluding remarks

This paper considers the effects of asymmetric access charge regulation as well as deregulation uncertainty on a pre-emptive investment strategy in an asymmetric market environment.

Our paper provides several important results. First, we show that an entrant with a cost disadvantage has an incentive to invest as a leader under uncertainty about deregulation of an asymmetric access charge. That is, an asymmetric access charge regulation may lead the entrant to enter the new market as a leader even under the potential threat of the removal of an asymmetric regulation. Second, an asymmetric access charge regulation may accelerate investment. This result leads to an increase in consumer surplus and a decrease in the producer surplus. However, note that the investment may be delayed when the asymmetric access charge is too small or too large. Third, we find that an increase in deregulation intensity may accelerate investment. Here again, the investment is decreased when deregulation intensity is too weak or too strong. That is, the competitive market environment is weaken if the deregulation intensity is extremely small or large. The implication for the regulation authority is that extremely weak or strong deregulation intensity should not be applied to stimulate investment. Finally, the investment is greatest when the completive market environment between two firms is completely symmetric, causing the fact that the consumer and producer surpluses to be highest and lowest, respectively. Thus, the more intense the competitive market environment is, the larger (smaller) is the consumer (producer) surplus. These results are consistent with those of previous empirical studies.

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	NTT docomo	KDDI	softbank
share (at the beginning of 2007FY)	52%	28%	16%
share (at the end of 2007FY)	50%	28%	17%
access charge estimate (by KDDI, 2007FY)	100	106	119
access charge estimate (by NTT docomo, 2007FY)	100	108	120

Market share is based on the user's number at April 1, 2007.

Table 1: Asymmetric access charge

	$x^*_{\mathrm{P}k}$	$x^*_{\mathrm{L}k}$	$x^*_{\mathrm{F}k}$
Incumbent (I)	0.2802	0.3531	0.7283
Entrant (E)	0.2371	0.3619	0.5230

Table 2: Investment triggers

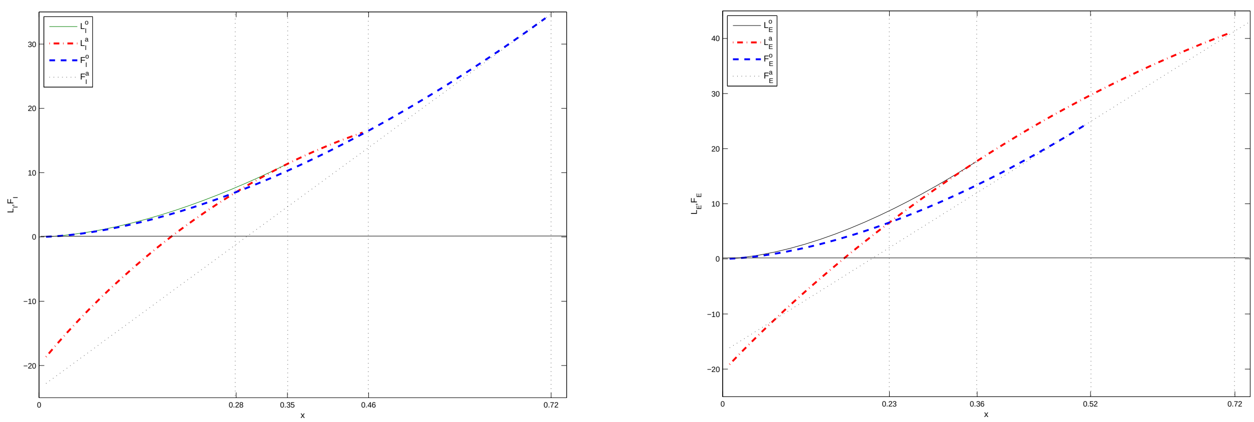

Figure 1: Value functions for the incumbent and the entrant

The left- and right-hand panels depict the value function for the incumbent and the entrant, respectively. Here, we have $x^*_{\mathrm{PI}} = 0.2802 > 0.2371 = x^*_{\mathrm{PE}}$ under these parameters. Then at the equilibrium, the entrant enters the market as a leader at x^*_{PI} while the incumbent enters the market as a follower at x^*_{FI}.

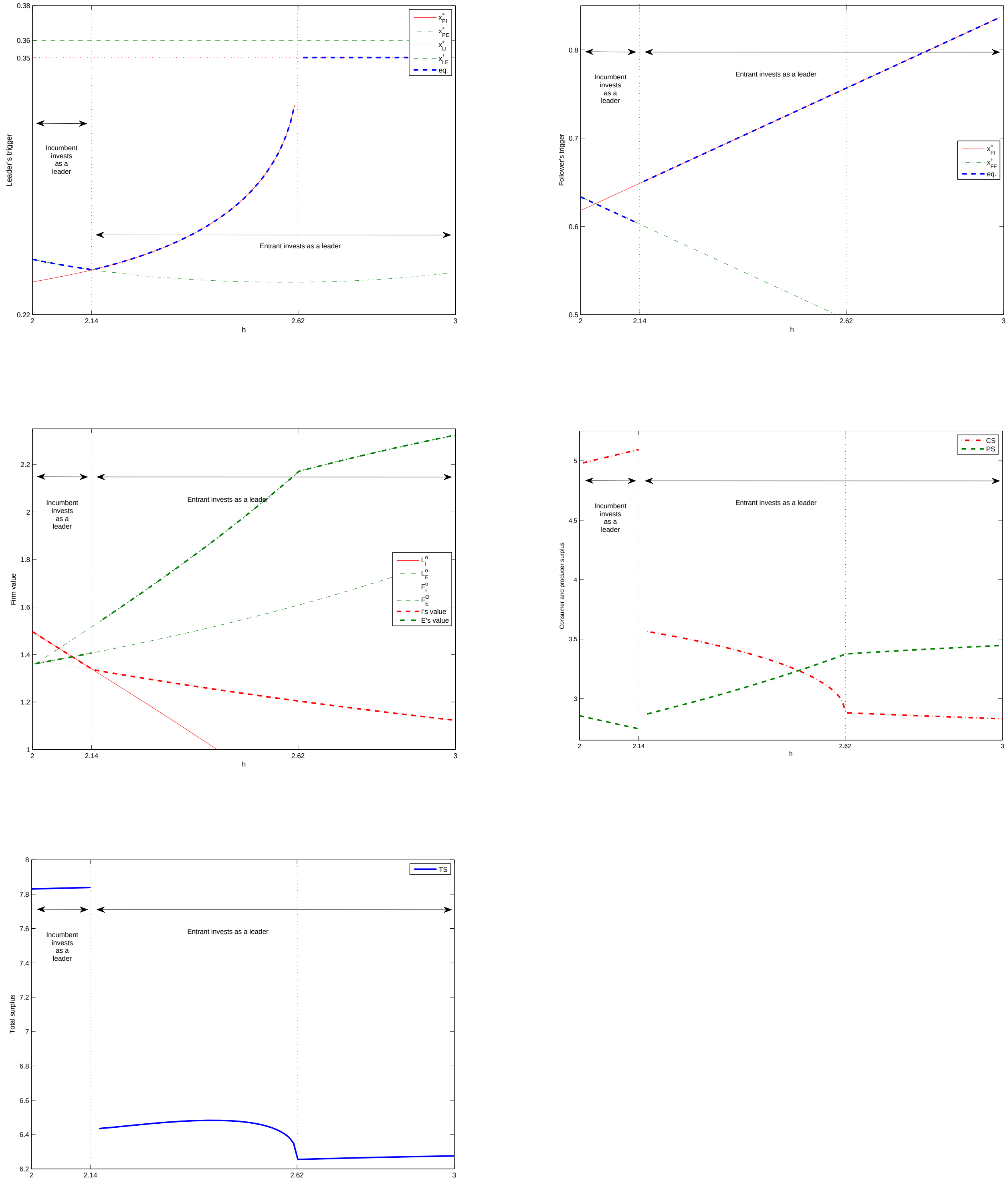

Figure 2: Effects of asymmetric access charge h

The top left- and right-hand panels depict the investment triggers of a leader and a follower, respectively. For $h < 2.14$, the incumbent enters the market as a leader. For $h > 2.14$, the entrant enters the market as a leader. The middle left-hand panel shows the firm values while the middle right-hand panel shows the consumer and producer surpluses. The consumer and producer surpluses are highest and lowest at $h = 2.14$ where the competitive environment is completely symmetric. The bottom left-hand panel shows the total surplus.

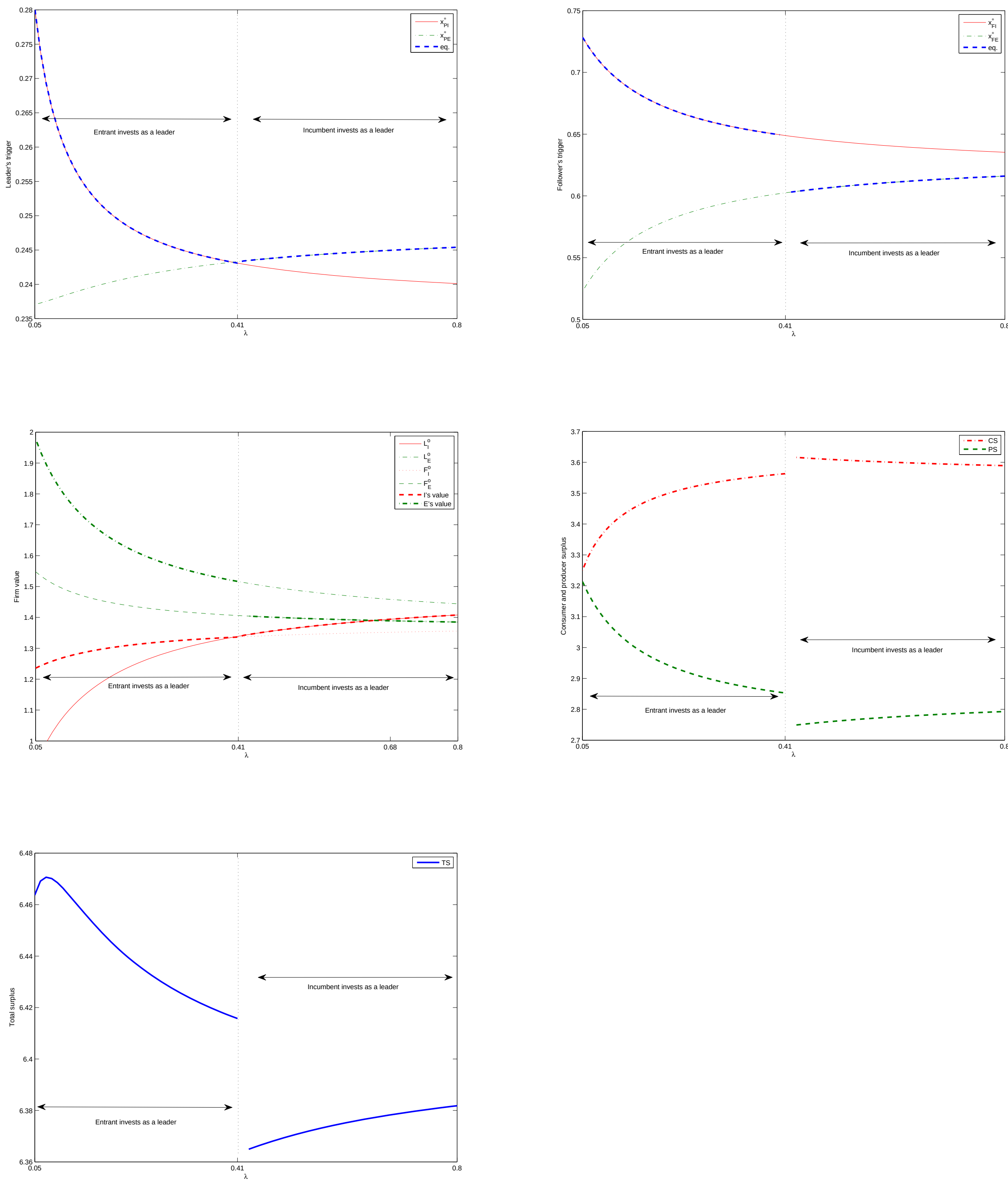

Figure 3: Effects of deregulation intensity λ

The top left- and right-hand panels depict the investment triggers of a leader and a follower, respectively. The middler left- and right-hand panels demonstrate the firm value and welfare, respectively. The bottom left-hand panel shows the total surplus. The consumer and producer surpluses are highest and lowest at $\lambda = 0.41$, respectively, where the competitive environment is completely symmetric $\lambda = 0.41$.

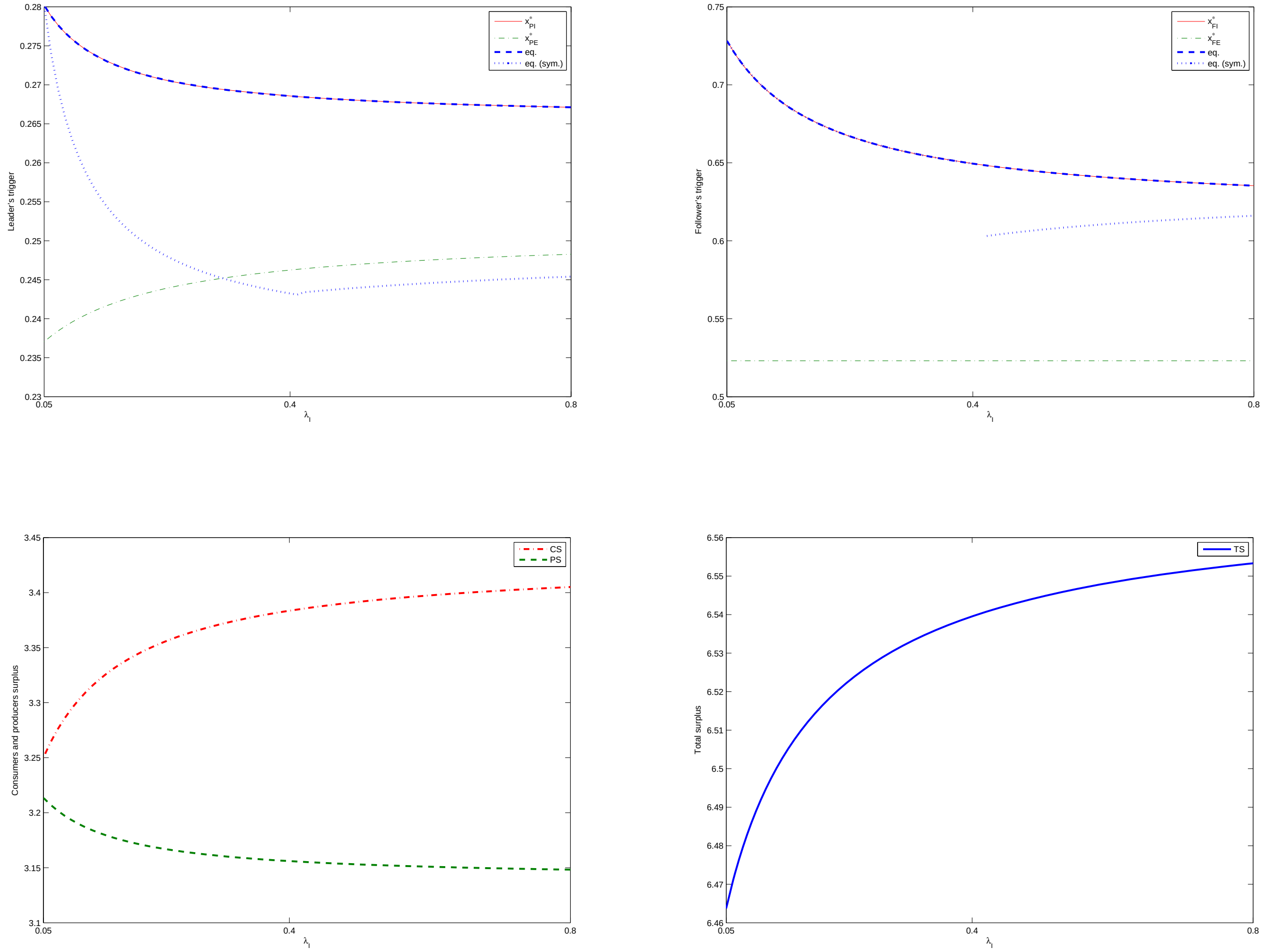

Figure 4: Effects of asymmetric deregulation intensity λ_{I}

This figure illustrates the effect of λ_{I} on the investment trigger of a leader (upper left panel), the investment trigger of a follower (upper right panel), the consumer and producer surpluses (lower left panel), and the total surplus (lower right panel).

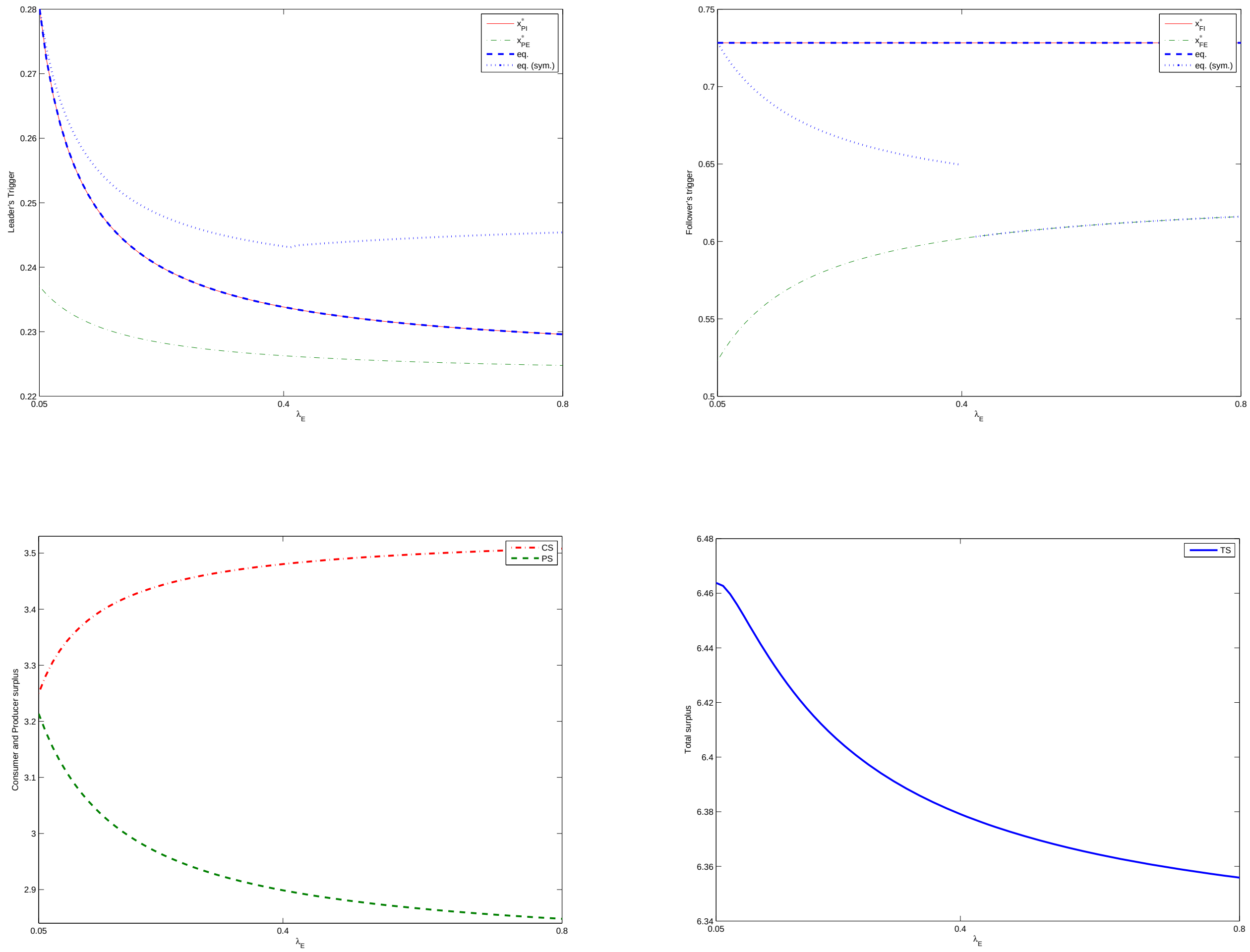

Figure 5: Effects of asymmetric deregulation intensity λ_{E}

This figure illustrates the effect of λ_{E} on the investment trigger of a leader (upper left panel), the investment trigger of a follower (upper right panel), the consumer and producer surpluses (lower left panel), and the total surplus (lower right panel).