Access Price Regulation and Strategic Infrastructure Investment*

Akira Ishii

Abstract

This paper analyzes the differential effects of equally restrictive access price regulations in an industry where a vertically integrated firm has a monopoly on the supply of an essential network service and also operates in a competitive product market. The vertically integrated firm invests strategically to reduce the cost of using the network before the market competition. Social welfare is maximized under a hybrid form of price-cap and cost-of-service regulations which induces a smaller cost reduction than price-cap regulation, when the vertically integrated firm produces at a sufficiently low marginal cost compared with its rival firms in the product market. Otherwise, it is maximized under price-cap regulation or under a hybrid form of price-cap and cost-of-service regulations which induces a larger cost reduction than price-cap regulation.

JEL classification: L43, L51, L97

Keywords: access price, infrastructure investment, vertically related markets

---

*We are grateful to Jun Wako, Hideki Konishi, Daisuke Shimizu, Keizo Mizuno, Noriyuki Doi, Tetsuya Shinkai, Ikuo Ishibashi, Noriaki Matsushima, and the seminar participants at Kwansei Gakuin and Sapporo Gakuin Universities and Competition Research Center of Japan Fair Trade Commission for their valuable and constructive suggestions. Of course, any remaining errors are my responsibility.

1 Introduction

The purpose of this paper is to investigate the differential effects of equally restrictive access price regulations in an industry where a vertically integrated firm has a monopoly on the supply of an essential network service and also operates in the competitive product market. In public utility industries, such as telecommunications, electricity generation, gas supply, and train services, no service can be supplied without access to essential network facility, which is generally monopolized. The examples for this are the networks for electricity and gas transmissions and railway tracks. Since the recent wave of the liberalization of potentially competitive sectors promotes new entry (for example, the liberalization of the retail electricity market in Japan), access price regulation becomes one of important policy issues in public utilities. In addition, the efficient and stable operation of essential facility is an important problem because there are concerns that the liberalization may discourage investment for using the infrastructures of public utilities more efficiently.

Main access price regulation was developed by cost-based approaches. The examples for this are Efficient Component Pricing Rule (ECPR) and Total Element Long Run Increment Cost (TELRIC).[1] Such cost-based regulation discourages a regulated firm from reducing its cost because the price is set such that the total revenue from each service covers the total cost in its production. Access price-cap regulation was also adopted in the interstate access charge in the U.S. telecommunications and non-competitive interconnection service in the U.K. telecommunications. Price-cap regulation provides a regulated firm with the incentive for cost reduction because the regulator sets a ceiling of the price which is charged by the firm. Price-cap regulation was recommended as an incentive regulatory method by Littlechild (1983) and subsequently has been adopted for many public utilities and privatized monopoly firms instead of cost-based regulations (e.g. British Telecom and AT&T). With such regulatory shift, the problems arising from price-cap regulation have been addressed by many economists.[2] The literature has only

[1] For the ECPR, which got into the limelight as an access pricing rule, see Willing (1979), Baumol (1983), Baumol and Sidak (1994a, 1994b), Kahn and Taylor (1994), Tye (1994), and Sidak and Spulber (1997). For the TELRIC, which stole the limelight from the ECPR, see Economides and White (1994, 1995) and Hausman (1997).

[2] Acton and Vogelsang (1989) provided the survey on the main issues and pioneering studies of price-cap regulation. For theoretical comparison of cost reduction under cost-based and price-cap regulations, see Cabral and Riordan (1989), Schmalensee (1989), Clemenz (1991), and Kidokoro (2002). For the price-caps which are converged on efficient price structures, see Bradley and Price (1988), Vogelsang (1989), and Brennan (1989). The deterioration of service quality under price-cap regulation was pointed out by

compared the effects of cost-based and price-cap regulations in a model of monopoly.[3]

We focus on access price regulation on a vertically integrated firm which monopolizes the supply of an essential network service and also operates in the competitive product market. When the product market is imperfectly competitive, the vertically integrated firm makes its infrastructure investment and output decisions strategically. Investment level is chosen not only to reduce the cost of using the network but also to make a credible commitment to higher output level and discourage the production of its rival firms. That is, the behavior of the vertically integrated firm is affected not only by the regulatory method of access price but also by the strategic interaction among firms in the product market. Therefore, in order to compare the relative performance of the regulation on access price charged by the vertically integrated firm, the analysis in consideration of the strategic interaction in the product market is also required.

We consider an industry where naturally monopolistic and competitive activities are vertically related. The incumbent has a monopoly on the supply of an essential network service and also competes with entrants in a homogeneous product market. Entrants can access the network if they pay an access price charged by the incumbent. The regulator imposes a regulatory constraint on access price, while it does not regulate the product market price, which is determined in the market. Three types of the regulatory methods is analyzed in the model: cost-of-service regulation, price-cap regulation, and a hybrid form of price-cap and cost-of-service regulations. Under cost-of-service regulation, access price is set such that the total revenue from the network service covers the total cost of operating the network. Under price-cap regulation, only a ceiling for access price is set. Under a hybrid form of price-cap and cost-of-service regulations, on the other hand, access price partially depends on the actual cost of network operation. The incumbent invests to reduce the cost of using the network. The regulator and the firms behave in three stages. In the first stage, the regulator chooses a regulatory method of access price. In the second, the incumbent strategically precommits itself to cost-reducing investment

---

Spence (1975), Vickers and Yarrow (1988), Noam (1991), Rovizzi and Thompson (1992), Kidokoro (2002), Sappington (2005), and Weisman (2005). For the problem of how price-cap should be revised when there exists asymmetric information between the regulator and the regulated firm, see Sibley (1989), Lewis and Sappington (1989), Earle et al. (2007). For the problem of regulating a firm serving both monopoly and competitive markets, see Bös (1978), Vogelsang and Finsinger (1979), Braeutigam and Panzar (1989), and De Fraja and Price (1999). For intertemporal price-cap regulation, see Hagerman (1990), Sappington and Sibley (1992), and Dobbs (2004). For the relationship between price-cap regulation on an essential network division and product market competition, see Reitzes (2008).

[3] See, for instance, Schmalensee (1989), Clemenz (1991), and Kidokoro (2002).

level and chooses an access price of the network. In the third, the incumbent and entrants choose their output levels in the Cournot fashion.

In order to compare different kind of regulatory methods, it is analyzed under equally restrictive regulations, in which access price is regulated such that the vertically integrated incumbent only earns zero profit at most from the network division. The main results are as follows. When the vertically integrated incumbent produces at a sufficiently low marginal cost compared to its rival entrants, social welfare is maximized under a hybrid form of price-cap and cost-of-service regulations which induces a smaller cost reduction than price-cap regulation. Otherwise, it is maximized under price-cap regulation or under a hybrid form of price-cap and cost-of-service regulations which induces a larger cost reduction than price-cap regulation.

Schmalensee (1989), Cremenz (1991), and Kidokoro (2002) compared the relative welfare effect of price-cap regulation with the equally restrictive cost-based regulation and a hybrid form of price-cap and cost-based regulations in a model of monopoly. They showed that price-cap regulation has a relative welfare advantage over equally restrictive cost-based regulation and a hybrid form of price-cap and cost-based regulations when cost-reducing investment is carried out and no cost uncertainty exists. Our results demonstrate that their analysis has a limitation in that the results do not survive in an industry where naturally monopolistic and competitive activities are vertically related. Schmalensee (1989) also compared the effects of price-cap and cost-based regulations with cost uncertainty, using a numerical simulation method. Kidokoro (2002) also compared them in the case of quality-improving investment. In such cases, they showed that social welfare is maximized under a hybrid form of price-cap and cost-based regulations. Our result is different from theirs in the following two points. First, our result is derived from different factors from theirs. The main factor of our result is the distortion of investment behavior from cost minimization caused by the strategic interaction in the product market. Second, we show that there exists the case where social welfare is maximized under a hybrid form of price-cap and cost-of-service regulations which induces a larger cost reduction than price-cap regulation. In the previous studies, only a hybrid form of price-cap and cost-of-service regulations which leads to a smaller cost reduction than price-cap regulation is analyzed.

The remainder of the paper is organized as follows. We present the model in Section 2 and characterize the equilibrium in Section 3. The effects of equally restrictive access price regulations are compared in Section 4. Concluding remarks are given in Section 5.

All proofs are presented in the appendix.

2 The model

Let us suppose that there exists an industry in which an incumbent competes with n identical entrants. The incumbent and entrants produce a homogeneous product. In order to supply one unit of the product, one unit of access to an essential network facility is required. We assume that the incumbent has a monopoly on the network operation and allows entrants to access the network at the price of a per unit of access. The access price that the incumbent charges entrants is regulated.

The incumbent incurs the production cost, $c_I x$, when it produces x units of the product, while entrant i $(i = 1, 2, \cdots, n)$ bears the production cost, $c_E y_i$, when it produces y_i units. The market demand is represented by an inverse demand function, $P = A - Q$, in which $A > 0$ and $Q = x + \sum_{i=1}^{n} y_i$. The total output level, Q, is assumed to be verifiable.[4] The incumbent invests in order to reduce the marginal cost of using the network. Let $\theta(k)$ be the marginal cost of using the network when the incumbent carries out k units of cost-reducing investment.

Assumption 1 *The cost function,* $\theta(k)$*, has the following properties:* (*i*) $\theta'(k) < 0$, $\lim_{k\to 0} \theta'(k) = -\infty$, *and* $\lim_{k\to +\infty} \theta'(k) = 0$; *and* (*ii*) $\theta''(k) > 0$.

The incumbent bears the total cost of the network service, $C = \theta(k) Q + F$, where F is the fixed cost, when it makes k units of cost-reducing investment and the total output level is Q. We assume that the regulator can observe the levels of the total and fixed costs of the network operation, C and F. This implies that the regulator can calculate the marginal cost level of using the network, $\theta(k)$, from the values of C, F, and Q.

For access price regulation, the regulator employs three regulatory methods: price-cap regulation, cost-of-service regulation, and a hybrid form of price-cap and cost-of-service regulations. In the model, for analytical simplicity, price-cap regulation is expressed as

$$a_B \geq a, \tag{1}$$

[4] This assumption is not unrealistic. For example, Japanese electric power companies must notify Ministry of Economy, Trade and Industry of their electric supply plans over the next decade.

where a_B is a constant base price per unit of access, which is determined by the regulator.[5] Under cost-of-service regulation, on the other hand, the regulator adjusts access price to be equal to the cost of providing the network service. We assume that the regulator can give the incumbent a lump-sum subsidy equal to the fixed cost of using the network, F.[6] Under this assumption, cost-of-service regulation can be expressed as

$$\theta(k)\sum_{i=1}^{n} y_i \geq a\sum_{i=1}^{n} y_i. \tag{2}$$

Dividing both sides of (2) by $\sum_{i=1}^{n} y_i$, cost-of-service regulation can be rewritten as

$$\theta(k) \geq a. \tag{3}$$

Combining (1) with (3), we obtain the following regulatory constraint that includes price-cap and cost-of-service regulations:

$$\theta(k) + \mu\{a_B - \theta(k)\} \geq a, \tag{4}$$

where $\mu \geq 0$. (4) reduces to cost-of-service regulation when $\mu = 0$, to price-cap regulation when $\mu = 1$, and to a hybrid form of price-cap and cost-of-service regulations otherwise. When $\mu > 0$, the regulator allows the incumbent to reserve the return on cost-reducing effort, which is expressed by the product of the rate of return, μ, and the difference between the base price and the marginal cost of using the network realized after the incumbent's cost-reducing investment, $a_B - \theta(k)$. The regulator imposes the regulatory constraint like (4)[7]. The regulatory constraint is assumed to bind access price in the equilibrium, though it does not have to be that way in the case where the base price is sufficiently high.[8]

[5] Littlechild (1983) recommended price-cap regulation in a dynamic framework: the ceiling price should change according to the $RPI - X$ rule, where RPI is the rate of change in the retail price index and X is the expected gain in the utility firm's efficiency.

[6] Who bears the fixed cost of essential facility is an important matter for the regulator. An increase in the incumbent's share of the fixed cost would reduce its investment. This paper does not consider the effect of the allocation rule of the fixed cost on investment.

[7] The interstate access service of local exchange carriers in the United States is an example of the regulatory method analyzed in the model. In 1995, the Federal Communications Commission provided the local exchange carriers three options for the productivity offset. The local exchange carriers that choose the highest offset are exempted from the profit sharing requirement, whereas they that choose the lowest offset have to receive a severe profit-sharing requirement. When choosing a higher productivity offset, the local exchange carriers face a lower base price, a_B, and a higher rate of return, μ, in the model.

[8] If the regulatory constraint is not binding , then the equilibrium must coincide with that under free access pricing by the incumbent.

It is necessary to analyze under equally restrictive regulations on access price in order to compare different kind of regulatory methods. For the reason, the regulator is assumed to determine the rate of return, μ, and then always set the base price, a_B, such that the incumbent's profit obtained from the network division is zero at most. That is, under any μ, a_B is set to the same level as the actual marginal cost of using the network, $\theta(k)$.[9] Therefore, under our assumptions, access price regulation imposes the zero-profit constraint on the network division, so that the incumbent only earns zero profit at most from the network division irrespective of the regulatory constraint.

The profit functions of the incumbent and entrant i $(i = 1, 2, \cdots, n)$ are written as respectively

$$\Pi = \{P(Q) - c_I - a\}x + \{a - \theta(k)\}Q - k \tag{5}$$

and

$$E_i = \{P(Q) - c_E - a\}y_i. \tag{6}$$

Social welfare is defined as the sum of economic surplus obtained by all participants: that is,

$$W \equiv CS + \Pi + \sum_{i=1}^{n} E_i - F, \tag{7}$$

where CS denotes consumers' surplus, which is defined as

$$CS \equiv \int_0^Q P(v)\,dv - P(Q)Q. \tag{8}$$

We analyze a three-stage game. In the first stage, the regulator chooses a rate of return on cost-reducing effort, μ, so as to maximize social welfare on the assumption that under any μ, the base price, a_B, is set to the same level as the expected marginal cost of using the network, $\theta(k)$, in full anticipation of the equilibria of the second and third stages. In the second, the incumbent chooses its investment level, k, and the price per unit of access to the network, a, so as to maximize its profit, taking as given the values of μ and a_B. In the third, the incumbent and n entrants choose their output levels in the Cournot fashion. Note that throughout the analysis, the policy variables do not change during the competition among firms in the second and third stages. We use subgame perfection as the equilibrium concept and solve this game by backward induction.

[9] This presupposes that the regulator can predict the gains in the productivity of the network division from the historical data on the incumbent's cost and the information on its current technology and R&D plan, even if the cost for a cost reduction of the network operation is unobservable.

3 Equilibrium

Before comparing the effects of equally restrictive regulations on investment, prices, profits, and social welfare, we examine the characteristics of the equilibrium in the model.

3.1 Equilibrium output

In the third stage, the incumbent chooses its output level, x, so as to maximize its profit, taking as given the values of its investment level, k, and the access price, a, chosen in the second stage and the output levels of entrant i ($i = 1, \cdots, n$), y_i. Entrant i ($i = 1, 2, \cdots, n$) also chooses its output level, y_i, so as to maximize its profit, taking as given the value of a determined in the second stage and the output levels of the incumbent and entrant j ($j \neq i$), x and y_j. Making use of (5) and (6), the first-order conditions for the profit maximization of the incumbent and entrant i are respectively

$$P(Q) - c_I - a + P'(Q)x + \{a - \theta(k)\}\frac{\partial Q}{\partial x} = 0 \tag{9}$$

and

$$P(Q) - c_E - a + P'(Q)y_i = 0. \tag{10}$$

The equilibrium output levels of the incumbent and entrant i ($i = 1, 2, \cdots, n$) for any relevant k, a, and n are respectively

$$x^*(k, a, n) = \frac{1}{n+2}\{A - (n+1)c_I + nc_E + na - (n+1)\theta(k)\} \tag{11}$$

and

$$y_i^*(k, a, n) = \frac{1}{n+2}\{A + c_I - 2c_E - 2a + \theta(k)\}. \tag{12}$$

In what follows, since entrants are identical, let $y^*(k, a, n)$ denote the symmetric equilibrium output level of each entrant for any k, a, and n. We will assume that $x^*(k, a, n) > 0$ and $y^*(k, a, n) > 0$, which hold if A is sufficiently large relative to c_I, c_E, and $\theta(0)$.

Making use of (11) and (12), the profit functions of the incumbent and entrant i ($i = 1, 2, \cdots, n$) are rewritten respectively as

$$\Pi^*(k, a, n) = x^*(k, a, n)^2 + \{a - \theta(k)\}ny^*(k, a, n) - k \tag{13}$$

and

$$E_i^*(k,a,n) = y^*(k,a,n)^2 . \quad (14)$$

3.2 Equilibrium access price and investment

In the second stage, given the values of μ and a_B set in the first stage, the incumbent solves the following constrained profit maximization problem:

$$\max_{k,a} \Pi^*(k,a,n)$$
$$\text{subject to } \theta(k) + \mu\{a_B - \theta(k)\} \geq a.$$

In order to state the first-order and second-order conditions for the maximization problem, we make the Lagrangian:

$$\Lambda(k,a,\lambda) = \Pi^*(k,a,n) + \lambda\{\mu a_B + (1-\mu)\theta(k) - a\}, \quad (15)$$

where λ is a Lagrangian multiplier. Let k^*, a^*, and λ^* be the solutions to the maximization problem. That is, k^* and a^* denote respectively the investment level and access price in the second-stage equilibrium.

Since we consider the case where the constraint is biding, that is, $\lambda > 0$, the first-order conditions are

$$\Lambda_k = -\frac{\theta'(k)}{n+2}[2(n+1)x^* + n(n+2)y^* - n\{a-\theta(k)\}] + \lambda(1-\mu)\theta'(k) - 1 = 0, \quad (16)$$

$$\Lambda_a = \frac{2n}{n+2}x^* + ny^* - \frac{2n}{n+2}\{a - \theta(k)\} - \lambda = 0, \quad (17)$$

and

$$\Lambda_\lambda = \mu a_B + (1-\mu)\theta(k) - a = 0, \quad (18)$$

where Λ_i $(i = k, a, \lambda)$ denotes $\partial\Lambda(k,a,\lambda)/\partial i$. From (18), the equilibrium access price is $a^*(\mu, a_B, k^*) = \theta(k^*) + \mu\{a_B - \theta(k^*)\}$. Substituting (17) and (18) into (16) yields

$$-\left[\left\{1 + \frac{(2\mu-1)n}{n+2}\right\}x^* + \mu n y^* - \frac{\mu(2\mu-1)n}{n+2}\{a_B - \theta(k^*)\}\right]\theta'(k^*) = 1. \quad (19)$$

The left-hand side (LHS) of (19) represents the marginal revenue from a marginal increase in investment at $k = k^*$, while the right-hand side (RHS) is equal to the marginal cost.

It is demonstrated in (19) that the strategic interaction in the output stage distorts the incumbent's investment behavior from cost minimization. When the regulator sets a_B to the level of $\theta(k^*)$ in advance, the production cost is minimized when the investment level satisfies $-(x^*+\mu ny^*)\theta'(k^*)=1$. Owing to the presence of the strategic interaction in the output stage, (19) validates that with $a_B=\theta(k^*)$, $-(x^*+\mu ny^*)\theta'(k^*) > (\textit{resp.} =, <)\ 1$ if and only if $\mu < (\textit{resp.} =, >)\ 1/2$. $-(x^*+\mu ny^*)\theta'(k^*) > (\textit{resp.} <)\ 1$ implies that the inefficiency is caused by *underinvestment* (*resp. overinvestment*) from the viewpoint of the incumbent's profit. The equilibrium investment level must satisfy (19). That is, in the second-stage equilibrium,

$$\theta'(k^*) = -\frac{n+2}{2(\mu n+1)x^* + \mu n(n+2)y^* + \mu(1-2\mu)n\{a_B-\theta(k^*)\}} \tag{20}$$

holds. With the assumption of $x^*>0$ and $y^*>0$, the condition of $\theta'(k^*)$ satisfied at the limits is sufficient to guarantee the existence of the second-stage equilibrium. In addition, to guarantee its uniqueness, the following assumption is made (see appendix C for the details of the uniqueness).

Assumption 2 *$\theta(k)$ is sufficiently convex such that $\theta''(k) > -\theta'(k)^3/2$ holds for any $k \geq 0$.*

3.3 Equilibrium regulatory constraint

Substituting $k=k^*(\mu,a_B,n)$ into (7) and (8) gives social welfare when the incumbent carries out k^* units of investment for any μ , a_B, and n:

$$W^*(\mu,a_B,k^*,n) = \int_0^{Q^*} P(Q)\,dQ - c_I x^* - c_E n y^* - \theta(k^*)Q^* - k^* - F, \tag{21}$$

where $x^*=x^*(\mu,a_B,k^*,n)$, $y^*=y^*(\mu,a_B,k^*,n)$, and $Q^*=Q^*(\mu,a_B,k^*,n)$.

In the first stage, the regulator chooses a rate of return, μ, so as to maximize social welfare within the limit of $\mu \geq 0$ under the zero-profit constraint on network division. To solve this social welfare maximization problem, we consider the following maximization problem:

$$\max_{\mu} W^*(\mu,a_B,k^*,n)$$
$$\text{subject to } \mu \geq 0.$$

In order to state the first-order and second-order conditions for the maximization problem, we make the Lagrangian:

$$\Psi(\mu,\psi) = W^*(\mu, a_B, k^*, n) + \psi\mu, \tag{22}$$

where ψ is a Lagrangian multiplier. Let μ^* and ψ^* be the solutions to the maximization problem. That is, μ^* denote the rate of return in the first-stage equilibrium. The first-order conditions are

$$\Psi_\mu = W_\mu^* + W_{a_B}^* \frac{\partial a_B}{\partial \mu} + W_k^* \frac{\partial k^*}{\partial \mu} + \psi = 0, \tag{23}$$
$$\Psi_\psi = \mu \geq 0,\ \psi\Psi_\psi = 0, \text{ and } \psi \geq 0,$$

where Ψ_i $(i = \mu, \psi)$ denotes $\partial\Psi(\mu,\psi)/\partial i$ and W_i^* $(i = \mu, a_B, k)$ $\partial W(\mu, a_B, k^*, n)/\partial i$.

Since we assume that access price is regulated such that the incumbent only makes zero profit at most from the network division, under the second-stage equilibrium, $a^*(\mu, a_B, k^*) - \theta(k^*) = \mu\{a_B - \theta(k^*)\} = 0$ holds. Differentiation of this identity leads to

$$\frac{\partial a_B}{\partial \mu} = -\frac{a_B - \theta(k^*)}{\mu} + \theta'(k^*)\frac{\partial k^*}{\partial \mu} \quad \text{for } \mu > 0. \tag{24}$$

Differentiating (21) and making use of (19) and (24), we obtain that

$$W_\mu^* + W_{a_B}^* \frac{\partial a_B}{\partial \mu} + W_k^* \frac{\partial k^*}{\partial \mu} = -\frac{\theta'(k^*)}{n+2}[(n+1)x^* + (n+3)ny^* - \mu n\{2x^* + (n+2)y^*\} - 2\mu\{a_B - \theta(k^*)\}]\frac{\partial k^*}{\partial \mu}. \tag{25}$$

Since $\partial k^*(\mu, a_B, n)/\partial\mu > 0$ holds, which will be proved in the proof of proposition 1 below (see appendix A), it can be easily confirmed that the RHS of (25) is positive for $\mu = 0$. Thus, under $a_B = \theta(k^*)$, the rate of return in the first-stage equilibrium is $\mu^* > 0$ such that the bracketed term in the RHS of (25) is zero. The fact that the RHS of (25) is positive for $\mu = 0$ assures the existence of the equilibrium rate of return. In addition to assumptions 1 and 2, we assume the following condition in order to guarantee its uniqueness (see appendix C for the details).

Assumption 3 $\theta(k)$ *is sufficiently convex such that under the zero-profit constraint on the network division,* $d^2W^*(\mu, a_B, k^*, n)/d\mu^2 < 0$ *holds for any* μ *and* n.

4 Non-equivalence under constrained entry

4.1 Investment, price, and profit

Let us begin our analysis by examining the effects of equally restrictive regulations on the equilibrium investment, access price, market price, and profits. The following proposition summarizes the results.

Proposition 1 *When the number of firms in the product market is fixed, under the zero-profit constraint on the network division, the investment increases, the access price falls, the market price falls, the incumbent's profit decreases for $\mu > 0$, and each entrant's profit increases as the value of μ increases.*

Proof. See appendix A.

Under price-cap regulation and a hybrid form of price-cap and cost-of-service regulations, the access price is higher than $\theta(k)$ by the return on cost-reducing effort, so that an increase in the value of μ makes the incumbent have a stronger incentive for cost-reducing investment. In expectation of a reduction in $\theta(k)$, the regulator reduces the level of the base price a_B, because it sets a_B such that the incumbent only earns zero profit at most from the network service. For the reasons, the investment level is increasing in μ.

An increase in the value of μ produces the effect of decreasing access price by inducing a larger cost-reducing investment, while it has the effect of increasing access price by offering a higher return on cost reduction. Under the zero-profit constraint on the network division, however, it produces a larger former effect than the latter, so that the access price falls as the value of μ increases.

Investment has two different effects on the output and profit of each entrant. One is a negative *business-stealing* effect: the incumbent can make a credible commitment to a higher output level when increasing its investment, which discourages the production of entrants and leads to their lower profits. The other is a positive *free-riding* effect: an increase in investment encourages the production of entrants and increases their profits through a reduction in the access price. When the incumbent marginally increases its investment under a regulation, the free-riding effect always dominates the other. Accordingly, an increase in the value of μ increases each entrant's output and profit levels, because it stimulates the cost-reducing investment. Despite the production expansion of entrants, because the entry into the product market is constrained, the incumbent find it best to increase its production, which leads to a lower market price.

Recall that with $\mu >$ (*resp.* $<$) $1/2$, an increase in investment aggravates (*resp.* alleviates) the inefficiency caused by overinvestment (*resp.* underinvestment) from the viewpoint of the incumbent's cost minimization, which yields a lower (*reps.* higher) profit of the incumbent. For the reason, because the investment and market competition increase as the value of μ increases, it is obvious that an increase in the value of μ at the equilibrium for $\mu \geq 1/2$ decreases the profit of the incumbent. When $\mu < 1/2$, on the other hand, it generates a larger profit-reducing effect by increased market competition than the profit-enhancing effect by the alleviation of inefficiency from underinvestment as long as $\mu > 0$, which leads to a smaller profit of the incumbent.

4.2 Social welfare

The next analysis deals with the effects of equally restrictive regulations on the equilibrium social welfare. Recall that the equilibrium rate of return is $\mu^* > 0$ such that with $a_B = \theta(k^*)$, $W^*_\mu + W^*_{a_B}(\partial a_B/\partial\mu) + W^*_k(\partial k^*/\partial\mu) = 0$ holds. Examining the sign of $W^*_\mu + W^*_{a_B}(\partial a_B/\partial\mu) + W^*_k(\partial k^*/\partial\mu)$, the following result is obtained.

Lemma 1 *Given any number of entrants, n, with $a_B = \theta(k^*)$, (i) there exists $\mu \in (1/2, 1)$ such that $W^*_\mu + W^*_{a_B}(\partial a_B/\partial\mu) + W^*_k(\partial k^*/\partial\mu) = 0$ holds if $ny^*/x^* < n-1$, (ii) there exists $\mu \in [1, 4/3)$ such that $W^*_\mu + W^*_{a_B}(\partial a_B/\partial\mu) + W^*_k(\partial k^*/\partial\mu) = 0$ holds otherwise.*

Proof. See appendix B.

In addition, comparing ny^*/x^* with $n-1$ gives the following lemma.

Lemma 2 *With $a_B = \theta(k^*)$, $ny^*/x^* >$ (resp. $=, <$) $n-1$ if and only if $c_E <$ (resp. $=, >$) $c_I + \Delta(k^*, n)$, where $\Delta(k^*, n) \equiv \{A - c_I - \theta(k^*)\}/n(n+1) > 0$.*

Proof. See appendix B.

Summarizing proposition 1 and lemmata 1 and 2, we obtain the following proposition.

Proposition 2 *When the number of firms in the product market is fixed, under the zero-profit constraint on the network division, social welfare is maximized under a hybrid form of price-cap and cost-of-service regulations with $\mu^* \in (1/2, 1)$ if $c_E > c_I + \Delta(k^*, n)$, under price-cap regulation if $c_E = c_I + \Delta(k^*, n)$, and under a hybrid form of price-cap and cost-of-service regulations with $\mu^* \in (1, 4/3)$ otherwise.*

Let us explain the intuition as to how the degree of the rate of return μ affects consumers' surplus and the joint profit of the incumbent and n entrants when the regulatory constraint is imposed such that the incumbent only earns zero profit at most from providing the network service to n entrants.

Under imperfect competition, the market price is higher than the marginal costs of firms. An increase in the value of μ under the zero-profit constraint on the network division increases the total output of the incumbent and n entrants (see the proof of proposition 1 in appendix A), so that it improves the inefficiency from underproduction, which leads to a larger consumers' surplus.

Under the zero-profit constraint on the network division, the effect of a marginal increase in the value of μ at the equilibrium for any μ on the joint profit of the incumbent and n entrants is expressed as with $a_B = \theta(k^*)$,

$$\begin{aligned}\frac{d\Pi^*(\mu, a_B, k^*, n)}{d\mu} &+ n\frac{dE^*(\mu, a_B, k^*, n)}{d\mu} \\ &= \frac{n\{2x^* + (n+2)y^*\}\theta'(k^*)}{n+2}\left[\mu - \frac{2y^*}{2x^* + (n+2)y^*}\right]\frac{dk^*}{d\mu}. \qquad (26)\end{aligned}$$

From proposition 1, (26) shows that the joint profit of the incumbent and n entrants is maximized at the equilibrium for $\mu = 2y^*/\{2x^* + (n+2)y^*\}$. This implies that a marginal increase in the value of μ at the equilibrium for $\mu < 2y^*/\{2x^* + (n+2)y^*\}$ alleviates the inefficiency from underinvestment from the viewpoint of the joint profit, which leads to a larger joint profit. Thus, from assumption 3, under the zero-profit constraint on the network division, for $\mu \leq 2y^*/\{2x^* + (n+2)y^*\}$, social welfare becomes larger as the rate of return μ is higher.

At the equilibrium for $\mu > 2y^*/\{2x^* + (n+2)y^*\}$, on the other hand, a marginal increase in the value of μ aggravates the inefficiency from overinvestment from the viewpoint of the joint profit. Whether the effect of alleviating the inefficiency from underproduction dominates that of aggravating the inefficiency from overinvestment or not depends on the difference between the marginal costs of the incumbent and each entrant and the number of entrants.

First, suppose that n entrants produce at a higher marginal cost than the incumbent such that $c_E > c_I + \Delta(k^*, n)$, that is, $ny^*/x^* < n-1$ holds. Then, although an increase in the value of μ improves the inefficiency from underproduction, the change in the regulatory method is costly because it expands the production of the incumbent and n entrants and increases the market share of n entrants whose production is inefficient compared to the incumbent: with $a_B = \theta(k^*)$,

$$n\frac{dy^*}{d\mu} - \frac{dx^*}{d\mu} = -\frac{(n-1)\,\theta'(k^*)}{n+2}\frac{dk^*}{d\mu} > 0 \text{ for } n \geq 2.$$

For the reason, there exists the regulatory method with $\mu^* \in (1/2, 1)$ such that a marginal increase in the value of μ at the equilibrium produces the aggravation effect of the inefficiency from overinvestment equal to the alleviation effect of the inefficiency from underproduction, while the latter effect is dominated by the former at the equilibrium under price-cap regulation. From assumption 3, this implies that social welfare is maximized under this hybrid form of price-cap and cost-of-service regulations.

Next, suppose that $c_E \leq c_I + \Delta(k^*, n)$, that is, $ny^*/x^* \leq n-1$ holds. Then, the alleviation of the inefficiency from underproduction by an increase in the value of μ is less costly than that in the case of $c_E > c_I + \Delta(k^*, n)$ because the marginal cost of n entrants is not sufficiently higher than that of the incumbent even if c_E is higher than c_I. For the reason, when $c_E < c_I + \Delta(k^*, n)$, there exists the regulatory method with $\mu^* \in (1, 4/3)$ such that a marginal increase in the value of μ at the equilibrium creates the aggravation effect of the inefficiency from overinvestment equal to the alleviation effect of the inefficiency from underproduction. When $c_E = c_I + \Delta(k^*, n)$, on the other hand, the both effects just offset each other at the equilibrium under price-cap regulation. Therefore, from assumption 3, this implies that social welfare is maximized under the hybrid form of price-cap and cost-of-service regulations with $\mu^* \in (1, 4/3)$ if $c_E < c_I + \Delta(k^*, n)$ and under price-cap regulation if $c_E = c_I + \Delta(k^*, n)$.

The previous studies showed that social welfare is maximized under a hybrid form of price-cap and cost-based regulations when cost uncertainty exists. However, our result is derived from different factors from the previous studies. The main factor of our result is the distortion of investment behavior from cost minimization caused by the strategic interaction in the product market. In addition, we show that there exists the case where social welfare is maximized under a hybrid form of price-cap and cost-of-service regulations which leads a larger cost reduction than price-cap regulation. In the previous studies, only a hybrid form of price-cap and cost-of-service regulations which gives a lower incentive to cost reduction than price-cap regulation is analyzed.

5 Concluding remarks

This paper analyzed the effects of access price regulation in an industry where a vertically integrated firm has a monopoly on the supply of an essential network service and also operates in the competitive product market. The vertically integrated firm invests to reduce the cost of using the network. When access price is regulated such that the vertically integrated firm only earns zero profit at most from the supply of the network service, the following two main findings are obtained. First, when the marginal cost of the vertically integrated firm is sufficiently lower than that of its rival firms, social welfare is maximized under a hybrid form of price-cap and cost-of-service regulations which induces a smaller cost reduction than price-cap regulation. Otherwise, it is maximized under price-cap regulation or under a hybrid form of price-cap and cost-of-service regulations which induces a larger cost reduction than price-cap regulation.

Although we have analyzed a very simplified situation where many features of public utilities and regulatory methods are abstracted, the results give the following policy implication. When deciding the regulatory method of access price in an industry where a vertically integrated firm has a monopoly on the supply of an essential network service and also operates in the competitive product market, the difference among the production costs of the vertically integrated firm and its rival firms in the product market and the number of firms in the product market should be also taken into consideration.

Appendix

A. Proof of Proposition 1

As a start, it is proved that $k^*(\mu, a_B, n)$ is increasing in μ and $a^*(\mu, a_B, k^*)$ is decreasing in μ. Totally differentiating (16)-(18), we obtain that

$$\begin{pmatrix} \Lambda_{kk} & \Lambda_{ka} & \Lambda_{k\lambda} \\ \Lambda_{ak} & \Lambda_{aa} & \Lambda_{a\lambda} \\ \Lambda_{\lambda k} & \Lambda_{\lambda a} & \Lambda_{\lambda\lambda} \end{pmatrix} \begin{pmatrix} dk^* \\ da^* \\ d\lambda^* \end{pmatrix} = \begin{pmatrix} \lambda^* \theta'(k^*) \\ 0 \\ -a_B + \theta(k^*) \end{pmatrix} d\mu + \begin{pmatrix} 0 \\ 0 \\ -\mu \end{pmatrix} da_B. \tag{A.1}$$

Due to the zero-profit constraint on the network division, $a^*(\mu, a_B, k^*) - \theta(k^*) = \mu\{a_B - \theta(k^*)\} = 0$ holds. Differentiating this identity, the following relationship among a_B, μ, and k^* under the second-order equilibrium is derived:

$$da_B = -\frac{a_B - \theta(k^*)}{\mu} d\mu + \theta'(k^*)\, dk^* \quad \text{for } \mu > 0. \tag{A.2}$$

Substituting (A.2) into (A.1) and arranging the terms, we finally obtain that

$$\begin{pmatrix} \Lambda_{kk} & \Lambda_{ka} & \Lambda_{k\lambda} \\ \Lambda_{ak} & \Lambda_{aa} & \Lambda_{a\lambda} \\ \Lambda_{\lambda k} + \mu\theta'(k^*) & \Lambda_{\lambda a} & \Lambda_{\lambda\lambda} \end{pmatrix} \begin{pmatrix} dk^* \\ da^* \\ d\lambda^* \end{pmatrix} = \begin{pmatrix} \lambda^*\theta'(k^*) \\ 0 \\ 0 \end{pmatrix} d\mu. \tag{A.3}$$

Making use of Cramer's rule, from (A.3), we obtain that

$$\frac{dk^*}{d\mu} = \frac{\begin{vmatrix} \lambda^*\theta'(k^*) & \Lambda_{ka} & \Lambda_{k\lambda} \\ 0 & \Lambda_{aa} & \Lambda_{a\lambda} \\ 0 & \Lambda_{\lambda a} & \Lambda_{\lambda\lambda} \end{vmatrix}}{D} = -\frac{\lambda^*\theta'(k^*)}{D} > 0$$

and

$$\frac{da^*}{d\mu} = \frac{\begin{vmatrix} \Lambda_{kk} & \lambda^*\theta'(k^*) & \Lambda_{k\lambda} \\ \Lambda_{ak} & 0 & \Lambda_{a\lambda} \\ \Lambda_{\lambda k} + \mu\theta'(k^*) & 0 & \Lambda_{\lambda\lambda} \end{vmatrix}}{D} = -\frac{\lambda^*\theta'(k^*)^2}{D} < 0,$$

where

$$D \equiv \begin{vmatrix} \Lambda_{kk} & \Lambda_{ka} & \Lambda_{k\lambda} \\ \Lambda_{ak} & \Lambda_{aa} & \Lambda_{a\lambda} \\ \Lambda_{\lambda k} + \mu\theta'(k^*) & \Lambda_{\lambda a} & \Lambda_{\lambda\lambda} \end{vmatrix} > 0,$$

which holds under assumption 2.

The proof that $P(Q^*)$ is decreasing in μ is straightforward. Making use of (11) and (12) gives

$$Q^*(k, a, n) = \frac{1}{n+2}\left\{(n+1)A - c_I - nc_E - na - \theta(k)\right\}. \tag{A.4}$$

Differentiating (A.4) evaluated at the second-stage equilibrium, $k = k^*(\mu, a_B, n)$ and $a = a^*(\mu, a_B, k^*)$, and making use of (A.2) yields

$$\frac{dQ^*(\mu, a_B, k^*, n)}{d\mu} = \frac{\partial Q^*}{\partial \mu} + \frac{\partial Q^*}{\partial a_B}\frac{da_B}{d\mu} + \frac{\partial Q^*}{\partial k}\frac{dk^*}{d\mu} = -\frac{(n+1)\theta'(k^*)}{n+2}\frac{dk^*}{d\mu}.$$

From $dk^*/d\mu > 0$, with $a_B = \theta(k^*)$, $dQ^*(\mu, a_B, k^*, n)/d\mu > 0$ for any μ, which leads to $dP(Q^*)/d\mu < 0$.

Next, let us prove that for $\mu > 0$, the incumbent's profit is decreasing in μ. Substituting $k = k^*(\mu, a_B, n)$ and $a = a^*(\mu, a_B, k^*) = \theta(k^*) + \mu\{a_B - \theta(k^*)\}$ into (13) and differentiating it leads to

$$\begin{aligned}\frac{d\Pi^*(\mu, a_B, k^*, n)}{d\mu} &= \frac{\partial \Pi^*}{\partial \mu} + \frac{\partial \Pi^*}{\partial a_B}\frac{da_B}{d\mu} + \frac{\partial \Pi^*}{\partial k}\frac{dk^*}{d\mu} \\ &= \frac{\mu n[2x^* + (n+2)y^* - 2\mu\{a_B - \theta(k^*)\}]\theta'(k^*)}{n+2}\frac{dk^*}{d\mu}.\end{aligned}$$

Hence, with $a_B = \theta(k^*)$, because $dk^*(\mu, a_B, n)/d\mu > 0$, $d\Pi^*(\mu, a_B, k^*, n)/d\mu \leq 0$ holds. As to the equilibrium profit of each entrant, differentiating (14) evaluated at $k = k^*(\mu, a_B, n)$ and $a = a^*(\mu, a_B, k^*)$ and making use of (A.2) gives

$$\begin{aligned}\frac{dE_i^*(\mu, a_B, k^*, n)}{d\mu} &= \frac{\partial E_i^*}{\partial \mu} + \frac{\partial E_i^*}{\partial a_B}\frac{da_B}{d\mu} + \frac{\partial E_i^*}{\partial k}\frac{dk^*}{d\mu} \\ &= -\frac{2\theta'(k^*)y^*}{n+2}\frac{dk^*}{d\mu},\end{aligned}$$

which, because $dk^*(\mu, a_B, n)/d\mu > 0$, leads to $dE_i^*/d\mu > 0$ under $a_B = \theta(k^*)$.■

B. Proof of Lemmata 1 and 2

(25) is rewritten as

$$\begin{aligned}&W_\mu^* + W_{a_B}^*\frac{\partial a_B}{\partial \mu} + W_k^*\frac{\partial k^*}{\partial \mu} \\ &\quad = \frac{n\{2x^* + (n+2)y^*\}\theta'(k^*)}{n+2}\left[\mu - \left\{1 - \frac{(n-1)x^* - ny^*}{2nx^* + n(n+2)y^*}\right\}\right]\frac{\partial k^*}{\partial \mu},\end{aligned}$$

where

$$\frac{1}{2} < 1 - \frac{(n-1)x^* - ny^*}{2nx^* + n(n+2)y^*} < \frac{4}{3}.$$

Hence, there exists $\mu \in (1/2, 1)$ such that $W_\mu^* + W_{a_B}^*(\partial a_B/\partial \mu) + W_k^*(\partial k^*/\partial \mu) = 0$ holds when $ny^*/x^* < n-1$, $W_\mu^* + W_{a_B}^*(\partial a_B/\partial \mu) + W_k^*(\partial k^*/\partial \mu) = 0$ holds under $\mu = 1$ when $ny^*/x^* = n-1$, and there exists $\mu \in (1, 4/3)$ such that $W_\mu^* + W_{a_B}^*(\partial a_B/\partial \mu) + W_k^*(\partial k^*/\partial \mu) = 0$ holds when $ny^*/x^* > n-1$.

Subtracting ny^* from $(n-1)\,x^*$ yields with $a_B = \theta\,(k^*)$,

$$(n-1)\,x^* - ny^* = \frac{n\,(n+1)}{n+2}\,\{c_E - c_I - \Delta\,(k^*, n)\}\,,$$

where

$$\Delta\,(k^*, n) \equiv \frac{1}{n\,(n+1)}\,\{A - c_I - \theta\,(k^*)\}\,.$$

It follows from $x^* > 0$ that $A - c_I - \theta\,(k^*) > 0$, which implies $\Delta\,(k^*, n) > 0$. ■

C. Uniqueness of the equilibrium

(i) Uniqueness of the second-stage equilibrium

The uniqueness of the second-stage equilibrium under constrained entry is guaranteed by the second-order condition for the incumbent's profit maximization. The second-order condition requires that the bordered Hessian matrix of the Lagrangian is negative definite. The bordered Hessian matrix is

$$\begin{pmatrix} \Lambda_{kk} & \Lambda_{ka} & \Lambda_{k\lambda} \\ \Lambda_{ak} & \Lambda_{aa} & \Lambda_{a\lambda} \\ \Lambda_{\lambda k} + \mu\theta'\,(k^*) & \Lambda_{\lambda a} & \Lambda_{\lambda\lambda} \end{pmatrix} = \begin{pmatrix} \frac{\theta''(k)}{\theta'(k)} + \frac{2\theta'(k)^2}{(n+2)^2} & \frac{n(n+4)\theta'(k)}{(n+2)^2} & (1-\mu)\,\theta'\,(k) \\ \frac{n(n+4)\theta'(k)}{(n+2)^2} & -\frac{2n(n+4)}{(n+2)^2} & -1 \\ \theta'\,(k) & -1 & 0 \end{pmatrix},$$

where $\Lambda_{ij} = \partial^2\Lambda/\partial i\partial j$ $(i, j = k, a, \lambda)$. The bordered Hessian matrix is negative definite if and only if

$$\begin{vmatrix} \Lambda_{kk} & \Lambda_{ka} & \Lambda_{k\lambda} \\ \Lambda_{ak} & \Lambda_{aa} & \Lambda_{a\lambda} \\ \Lambda_{\lambda k} + \mu\theta'\,(k^*) & \Lambda_{\lambda a} & \Lambda_{\lambda\lambda} \end{vmatrix} > 0. \tag{A.5}$$

(A.5) holds if $\Lambda_{kk} < 0$ and

$$\Lambda_{kk}\Lambda_{aa} - \Lambda_{ka}\Lambda_{ak} = -\frac{2n\,(n+4)}{(n+2)^2}\left\{\frac{\theta''\,(k)}{\theta'\,(k)} + \frac{\theta'\,(k)^2}{2}\right\} > 0,$$

which are assured by assumption 2.

(ii) Uniqueness of the first-stage equilibrium

Totally differentiating (21) and making use of Young's theorem, we obtain the second-order condition for the social welfare maximization problem in the first-stage:

$$\frac{d^2W^*(\mu, a_B, k^*, n)}{d\mu^2} = W^*_{kk}\left(\frac{dk^*}{d\mu}\right)^2 + W^*_{a_Ba_B}\left(\frac{da_B}{d\mu}\right)^2 + 2W^*_{a_Bk}\frac{dk^*}{d\mu}\frac{da_B}{d\mu} + 2W^*_{\mu k}\frac{dk^*}{d\mu} + 2W^*_{\mu a_B}\frac{da_B}{d\mu} + W^*_{\mu\mu}, \quad \text{(A.6)}$$

where

$$W^*_{kk} = \frac{\partial^2 W^*}{\partial k^2} = -\frac{\theta''(k^*)}{n+2}\{(n+\mu n+3)x^* + n(n-2\mu+3)y^*\} + \frac{\theta'(k^*)^2}{(n+2)^2}(n+\mu n+3)(n-\mu n+1), \quad \text{(A.7)}$$

$$W^*_{a_Ba_B} = \frac{\partial^2 W^*}{\partial a_B{}^2} = -\frac{\mu^2 n^2}{(n+2)^2},$$

$$W^*_{a_Bk} = \frac{\partial^2 W^*}{\partial a_B \partial k} = \frac{\mu n\theta'(k^*)}{(n+2)^2}[n+5-\mu(n+8)],$$

$$W^*_{\mu k} = \frac{\partial^2 W^*}{\partial \mu \partial k} = \frac{n\theta'(k^*)}{n+2}\left[x^* + (n+4)y^* + \frac{n+5-\mu(n+8)}{n+2}\{a_B - \theta(k^*)\}\right],$$

$$W^*_{\mu a_B} = \frac{\partial^2 W^*}{\partial \mu \partial a_B} = -\frac{\mu n^2\{a_B - \theta(k^*)\}}{(n+2)^2}$$

and

$$W^*_{\mu\mu} = \frac{\partial^2 W^*}{\partial \mu^2} = -\frac{n^2\{a_B - \theta(k^*)\}^2}{(n+2)^2}.$$

With $a_B = \theta(k^*)$, (A.6) can be rewritten as

$$\frac{d^2W^*}{d\mu^2} = \left[W^*_{kk} + W^*_{a_Ba_B}\theta'(k^*)^2 + 2W^*_{a_Bk}\theta'(k^*)\right]\left(\frac{dk^*}{d\mu}\right)^2 + 2W^*_{\mu k}\frac{dk^*}{d\mu}. \quad \text{(A.8)}$$

Since from (A.7), $W^*_{kk} < 0$ if and only if

$$\theta''(k^*) > \frac{(n+\mu n+3)(n-\mu n+1)}{(n+2)\{(n+\mu n+3)x^* + n(n-2\mu+3)y^*\}}\theta'(k^*)^2 > 0$$

and $dk^*(\mu, a_B, n)/d\mu > 0$, $d^2W^*/d\mu^2 < 0$ holds if $\theta(k)$ is sufficiently convex such that with $a_B = \theta(k^*)$, the sign of the RHS of (A.8) is negative for any μ and n.

References

[1] Acton, J. P. and I., Vogelsang, 1989. Price-cap regulation: introduction. *RAND Journal of Economics* **20**, 369-372.

[2] Baumol, W. J., 1983. Some subtle issues in railroad regulation. *International Journal of Transport Economics* **10**, 341-355.

[3] Baumol, W. J. and J. G., Sidak, 1994a. *Toward Competition in Local Telephony*. Cambridge, MA.: MIT Press.

[4] Baumol, W. J. and J. G., Sidak, 1994b. The pricing of inputs sold to competitors. *Yale Journal on Regulation* **11**, 171-202.

[5] Bös, D., 1978. Cost of living indices and public pricing. *Economica* **45**, 59-69.

[6] Bradley, I. and C., Price, 1988. The economic regulation of private industries by price constraints. *Journal of Industrial Economics* **37**, 99-106.

[7] Braeutigam, R. R. and J. C., Panzar, 1989. Diversification incentives under "price-based" and "cost-based" regulation. *RAND Journal of Economics* **20**, 373-391.

[8] Brennan, T. J., 1989. Regulating by capping prices. *Journal of Regulatory Economics* **1**, 133-147.

[9] Cabral, L. M. B. and M. H. Riordan, 1989. Incentives for cost reduction under price cap regulation. *Journal of Regulatory Economics* **1**, 93-102.

[10] Clemenz, G., 1991. Optimal price-cap regulation. *Journal of Industrial Economics* **39**, 391-408.

[11] De Fraja, G. and C. W., Price, 1999. Regulation and access pricing: comparison of regulated regimes. *Scottish Journal of Political Economy* **46**, 1-16.

[12] Dobbs, I. M., 2004. Intertemporal price cap regulation under uncertainty. *Economic Journal* **114**, 421-440.

[13] Earle, R., K., Schmedders, and T., Tatur, 2007. On price caps under uncertainty. *Review of Economic Studies* **74**, 93-111.

[14] Economides, N. and L. J., White, 1994. Networks and compatibility: implications for antitrust. *European Economic Review* **38**, 651-662.

[15] Economides, N. and L. J., White, 1995. Access and interconnection pricing: how efficient is the efficient component pricing rule? *Antitrust Bulletin* **40**, 557-579.

[16] Hagerman, J., 1990. Regulation by price adjustment. *RAND Journal of Economics* **21**, 72-82.

[17] Hausman, J. A., 1997. Valuing the effect of regulation on new services in telecommunications. *Brookings Papers on Economic Activity, Microeconomics*, 1-38.

[18] Kahn, A. E. and W. E., Taylor, 1994. The pricing of inputs sold to competitors: a comment. *Yale Journal on Regulation* **11**, 225-240.

[19] Kidokoro, Y., 2002. The effect of regulatory reform on quality. *Journal of the Japanese and International Economies* **16**, 135-146.

[20] Lewis, T. R. and D. E. M., Sappington, 1989. Regulatory options and price-cap regulation. *RAND Journal of Economics* **20**, 405-416.

[21] Littlechild, S. C., 1983. Regulation of British Telecommunications' profitability. Report to the Secretary of State, Department of Industry, London.

[22] Noam, E. M., 1991. The quality of regulation in regulating quality: a proposal for an integrated incentive approach to telephone service performance. In M. A. Einhorn (ed.), *Price Caps and Incentive Regulation in Telecommunications*. Norwell, MA.: Kluwer Academic Publishers.

[23] Reitzes, J. D., 2008. Downstream price-cap regulation and upstream market power. *Journal of Regulatory Economics* **33**, 179-200.

[24] Rovizzi, L. and D., Thompson, 1992. The regulation of product quality in the public utilities and the citizen's charter. *Fiscal Studies* **13**, 74-95.

[25] Sappington, D. M., 2005. Regulating service quality: a survey. *Journal of Regulatory Economics* **27**, 123-154.

[26] Sappington, D. E. M. and D. S., Sibley, 1992. Strategic nonlinear pricing under price-cap regulation. *RAND Journal of Economics* **23**, 1-19.

[27] Schmalensee, R., 1989. Good regulatory regimes. *RAND Journal of Economics* **20**, 417-436.

[28] Sibley, D., 1989. Asymmetric information, incentives and price-cap regulation. *RAND Journal of Economics* **20**, 392-404.

[29] Sidak, J. G. and D. F., Spulber, 1997. *Deregulatory Takings and the Regulatory Contract: the Competitive Transformation of Network Industries in the United States*. Cambridge: Cambridge University Press.

[30] Spence, A. M., 1975. Monopoly, quality, and regulation. *Bell Journal of Economics* **6**, 417-429.

[31] Tye, W. B., 1994. The pricing of inputs sold to competitors: a response. *Yale Journal on Regulation* **11**, 203-224.

[32] Vickers, J. and G., Yarrow, 1988. *Privatization: an Economic Analysis*. Cambridge, MA.: MIT Press.

[33] Vogelsang, I., 1989. Price cap regulation of telecommunications services: a long-run approach. In M. A. Crew (ed.), *Deregulation and Diversification of Utilities*, Norwell, MA.: Kluwer Academic Publishers.

[34] Vogelsang, I. and J., Finsinger, 1979. A regulatory adjustment process for optimal pricing by multiproduct monopoly firms. *Bell Journal of Economics* **10**, 157-171.

[35] Weisman, D. L., 2005. Price regulation and quality. *Information Economics and Policy* **17**, 165-174.

[36] Willing, R. D., 1979. The theory of network access pricing. In H. M. Trebing (ed.), *Issues in Public Utility Regulation, East Lansing*, MI.: Michigan State University.