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INCENTIVES FOR COST REDUCTION UNDER PRICE CAP REGULATION

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1. Introduction

In this article, we present a formal analysis of the incentives for cost reduction under a regime of price-cap regulation. We assume price-cap regulation establishes a ceiling below which a monopolist has complete price flexibility, while prices above the ceiling are subject to cost-based regulation. Our main conclusions are that a marginal reduction in the price cap increases the regulated firm's investment in cost reduction. However, very low price caps might destroy investment incentives completely. Therefore, investment is a discontinuous function of the price-cap level.

Our analysis includes a stylized comparison between price-cap regulation and rate-of-return regulation. We show that investment in cost reduction is higher under an optimal price-cap regime. However, while expected cost is lower under price cap regulation, the same is not necessarily true for expected price.

The article is organized as follows. The next section introduces the basic results for the case when there is no cost uncertainty, and the following section generalizes these results. The comparison between price-cap regulation and rate-of-return regulation is the object of the next section. The final section includes concluding remarks.

2. Monopoly Regulation

Throughout the article, we assume that the market for telecommunications is a monopoly. This is the case of local exchange carriers, for practical purposes. While the market for domestic long distance service is not a monopoly, the present

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analysis provides a useful benchmark for examining the dominant firm case, and the key tradeoffs are in fact very similar for the two cases.[1]

We thus consider a monopolized market where the rate of demand is bounded and given by $D(P)$, with $dD/dP < 0$. Marginal cost is a function of an investment devoted to cost reduction. Specifically, denote by e the level of investment ("effort") in cost reduction and define Δ as the lag between the time of investment (normalized to $t = 0$) and the time when the cost reduction occurs. Then, marginal cost is $C(0)$ for $t < \Delta$, and $C(e)$ for $t > \Delta$. We assume that $C(e) \geq 0$, $0 < -dC/de < \infty$, and C is invariant with quantity produced.

Price-cap regulation is portrayed as follows. The regulator sets an initial price cap P_0 and an adjustment term x to take place at time Δ. The firm then makes an investment e in cost reduction. At time Δ, it can unilaterally set any price below $P_0 - x$, or it can request a rate hearing, the outcome of which is that the regulator sets price equal to C. We assume the regulation horizon is T years, $T \geq \Delta$.[2]

Since $C(0)$ is exogenously given and known to the regulator, it is no loss of generality to assume that P_0 is chosen such that the firm finds it optimal to set price equal to P_0 for $t < \Delta$. For the most part, our analysis focuses on the firm's pricing decision for $t > \Delta$.

Denote by $M(C)$ the firm's unconstrained monopoly price, which we assume is unique for any cost level C. Under price-cap regulation, the firm's actual price is given by

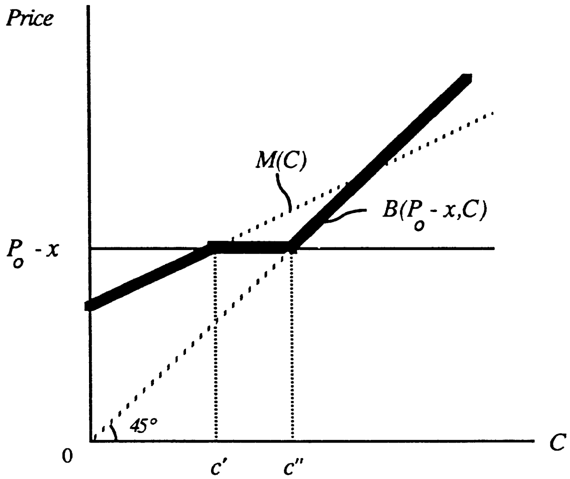

FIGURE 1: PRICE AS A FUNCTION OF COST UNDER PRICE CAP REGULATION.
$M(C)$: UNCONSTRAINED MONOPOLY PRICE;
P: PRICE CAP; $B(P,C)$: PRICE ACTUALLY SET.

$$B(P_0 - x, C) = \max\{C, \min\{P_0 - x, M(C)\}\} \quad (1)$$

This function is depicted in figure 1. For values of cost lower than c', the firm prices as an unconstrained monopolist. If C lies between c' and c'', then the price cap $P_0 - x$ is binding. Finally, if cost is higher than c'', the firm requests a rate hearing and price is set equal to marginal cost.

The firm's optimization problem can be described as

$$\max_e \pi(P_0 - x, e) \equiv [B(P_0 - x, C(e)) - C(e)]\, D[B(P_0 - x, C(e))] - e.^3 \quad (2)$$

Denote by $e^*(x)$ the solution to this problem. The first thing to notice about the monopolist's problem is that when price-cap regulation is too "tight" then there is no incentive for cost reduction. A very low price cap cannot possibly compensate the firm for an amount of effort sufficient to reduce cost below the price cap. Formally:

Proposition 2.1. Suppose that $e(0) > 0$. Then, there exists an x^* such that $e^*(x) = 0$ for $x > x^*$ and $e^*(x) > 0$ for $x < x^*$.[4]

The formal proof of this and the following propositions may be found in the Appendix. Our next result is that an increase in x (a decrease in the price cap) marginally increases the level of investment in cost reduction.

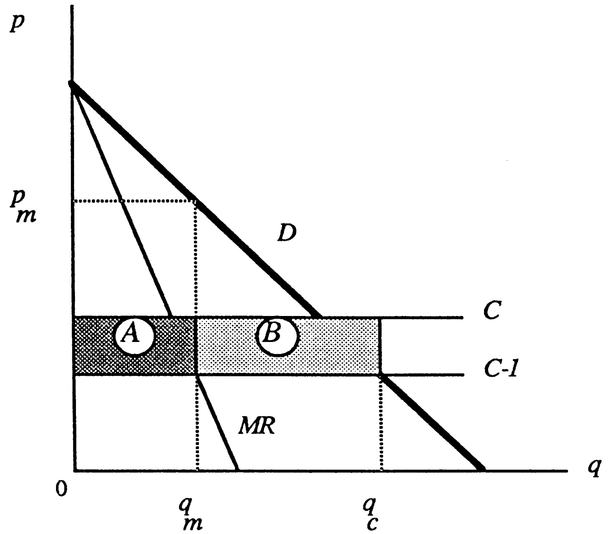

FIGURE 2: RETURNS ON COST REDUCTION
UNDER COMPETITIVE AND MONOPOLISTIC CONDITIONS

Proposition 2.2. If the price cap is binding and the firm's problem has an interior solution, then the optimal level of investment in cost reduction is increasing in x, i.e., $de^*/dx \geq 0$ for $x < x^*$.[5]

The explanation for the result lies in what is known as the "Arrow effect." In a seminal study, Arrow (1962) compared the incentives for process innovation under a monopolistic and a competitive downstream market. He concluded that the returns to R&D are greater under competition than under monopoly:

> The monopolist's incentive is always less than the cost reduction on the postinvention monopoly output, which in this case is, in turn, less than competitive output. . . . Since the inventor's incentive under competition is the cost reduction on the competitive output, it will again always exceed the monopolist's incentive. (p. 621)

In other words, a monopolist achieves a higher price by restricting quantity. Consequently, the savings from a reduction in unit cost are applied to a smaller number of units. This is illustrated in figure 2. The value of a one-dollar reduction in marginal cost is worth the area A+B under competitive conditions, while for a monopolist it is only worth A. Raising the price cap leads the regulated firm to a situation closer to the monopolistic one.

Finally, Propositions 2.1 and 2.2 imply the following corollary.

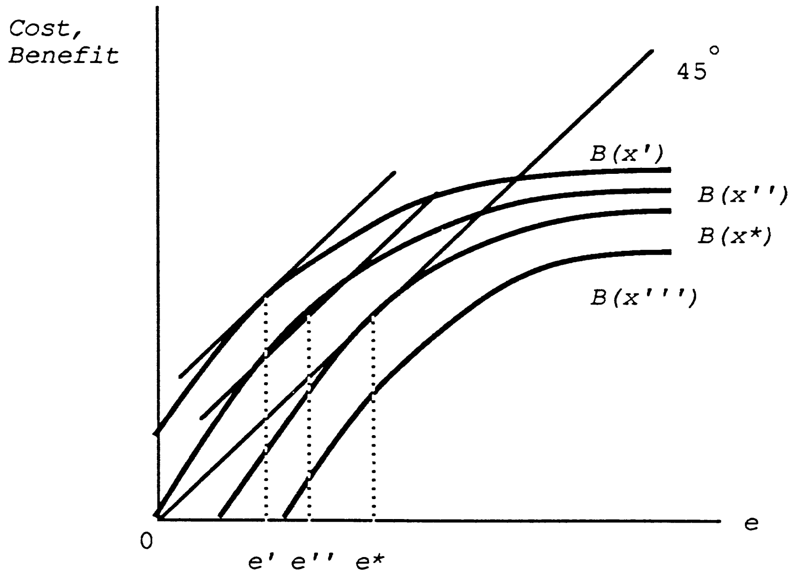

FIGURE 3: EXPECTED BENEFIT AS A FUNCTION OF e AND x.

Corollary 2.3. $e^*(x)$ is maximized at x^*.

These ideas can be understood from figure 3, which illustrates the net profitability of expenditures in cost reduction. The 45° line measures the direct cost of R&D effort. The remaining family of curves illustrates the expected profits from cost reduction for different levels of the adjustment term x. A higher value of x shifts expected benefits downward.

Two important effects are illustrated. First, if x is above some critical level x^* then expected net benefit from cost reduction is maximized at $e = 0$. Thus the firm will not make any investment in cost reduction unless x is sufficiently low.

Second, if x is below x^*, then the firm will optimally choose a strictly positive level of cost reduction effort that equates marginal benefit to marginal cost. That is, at an optimum, the slope of the expected benefit curve is equal to the slope of the 45° line. Thus, for x equal to x' (x'') the firm invests e' (e'').

Finally, for values of x below x^*, optimal R&D effort is increasing with x, i.e., a lower price cap encourages cost reduction.

3. Cost Uncertainty

In the previous section, we treated second-period cost as a deterministic function of investment in cost reduction. In this section, we generalize the main results to the case when costs are uncertain.

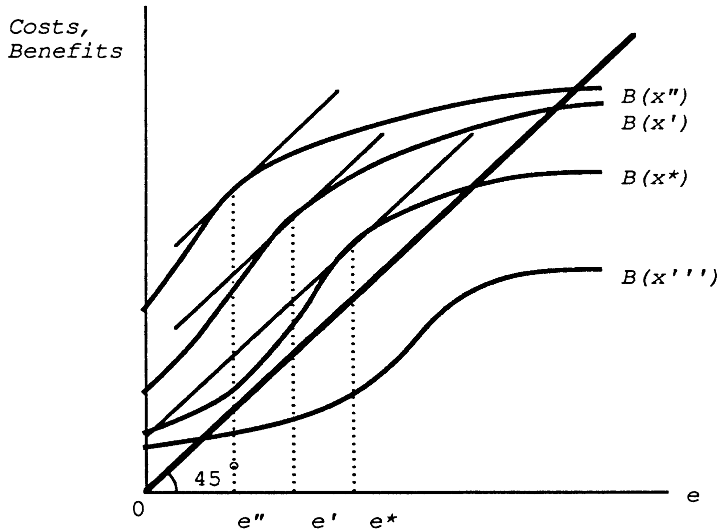

FIGURE 4:EXPECTED BENEFIT AS A FUNCTION OF e AND x.

Suppose that actual cost is a random variable c with a cumulative distribution $F(c \mid e)$ that depends on the level of investment in cost reduction. We assume that the support of c is contained in $[0, c^0]$, where c^0 is the initial cost, and that $\partial F/\partial e > 0$, that is more effort makes lower cost realizations more likely.[5]

Proposition 3.1. For low values of x, the optimal level of investment in cost reduction is increasing in x, i.e., $\left.\frac{\partial e^*}{\partial x}\right|_{x=0} > 0.$

Proposition 3.2. There exists x^* such that $e^*(x) = 0$ for $x > x^*$.

Example. Suppose that $P_0 = c^0 = 1$, $D(p) = \alpha - p$, and marginal cost is uniformly distributed on $[0, \exp(\beta e)]$, where α and β are constants. Figure 4 depicts expected benefit and the firm's optimal solution for different values of x. Notice that in contrast with figure 3 (certainty case) expected benefit is always positive, because some cost reduction occurs even when $e = 0$. Therefore, at the point of discontinuity, where the firm is indifferent between $e^* = 0$ and a positive value of e^*, net expected benefit is positive. Other than this, the discussion on the qualitative properties of figure 3 can be extended to figure 4.

Based on figure 4, we can map the optimal value e^* as a function of x. This is done in figure 5, for particular values of α and β ($\alpha = 2.05$ and $\beta = 2$). The main points of Propositions 2.1-2.3 are depicted in this figure: (1) for low values of x the optimal level of investment is increasing with x; (2) there is a level x^* such that

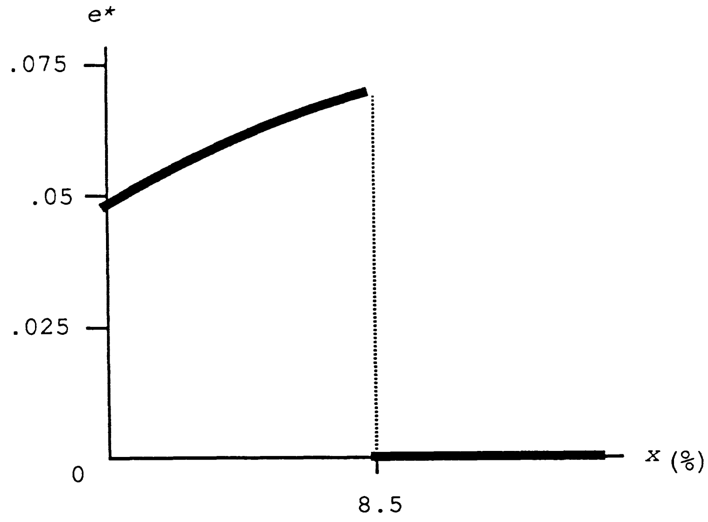

FIGURE 5: INVESTMENT IN COST REDUCTION AS A FUNCTION OF x.

$e^* = 0$ for $x > x^*$ and $e^* > 0$ for $x < x^*$; (3) e^* is maximized at $x = x^*$ (approximately 8.5% in this example). Note, however, that the characterization of Propositions 3.1 and 3.2 is not as complete as that of Propositions 2.1-2.3. In order for the latter to extend to the uncertainty case, we need the uncertain cost distribution to be sufficiently "close" to the certainty case. In general, we can only characterize the behavior of $e^*(x)$ for very low and very high values of x.

Comparison with Cost-Based Regulation

Cost-based regulation with regulatory lag is portrayed as follows. At time zero, a rate hearing occurs and price is set equal to cost c^0. This price remains valid until time T, when a new regulatory hearing occurs. We assume that $T > \Delta$. This implies that there is a positive incentive for investment in cost reduction, for the benefits of a lower cost during the period $[\Delta, T]$ remain with the firm. However, we will show that these benefits are weakly lower than under price-cap regulation.

In order to make a comparison between the two regimes, we assume that the second-period price cap remains valid for a length of time δ. It seems reasonable to suppose that $\Delta + \delta \geq T$, i.e., switching to the price-cap regime will not shorten the period of time the regulator can commit to.

Price-cap regulation can be understood as cost-based regulation with a (possibly) longer period of regulatory lag and downward price flexibility. Both of these differences tend to promote investment in cost reduction.

Proposition 4.1. The level of investment in cost reduction is the same or lower under cost-based regulation than under price-cap regulation.

This conclusion is easily understood in terms of the Arrow effect and well-known results in the regulatory lag literature (e.g., Baumol and Klevorick, 1970). Consider price-cap regulation when $P_0 = c^0$, $x = 0$, and $\delta = T - \Delta$. In this case the only difference between price-cap regulation and cost-based regulation is that the former allows downward price flexibility. By the Arrow effect, this difference promotes incentives for cost reduction. Moreover, the level of investment in cost reduction is nondecreasing in δ, which determines the length of time over which the firm is able to appropriate the benefits of cost reduction.

Another important point of comparison between price-cap and cost-based regulation is the level of prices in each regime. Under cost-based regulation, initial price is set at the level of initial cost c^0. This price is maintained for a period T, and then revised to the level of cost at time T, which is a function of the firm's optimal level of investment. Under price-cap regulation, the firm is free to set any price lower or equal to $P^0 - x$ during the period $[\Delta, \Delta + \delta]$. Note that given the assumptions previously made, the period $[\Delta, \Delta + \delta]$ can be subdivided into $[\Delta, T]$ and $[T, \Delta+\delta]$. Since, $P^0 - x$ is less than c^0, we can be sure that during the period $[\Delta, T]$ prices will be lower under price-cap regulation than under cost-based regulation. However, the same is not true for the period $[T, \Delta + \delta]$. The intuition for this result can be seen from figure 1. Suppose, for simplicity, that $P^0 - x = c^0$.

Under price cap regulation, in order for price to be lower than c^0 during the period $[T, \Delta + \delta]$, it must be the case that cost at time T is lower than c'; and even if this is the case price declines at a lower rate than cost.[6] Under cost-based regulation, however, *any* value of c below c^0 translates into a lower price during the period $[T, \Delta + \delta]$.

We thus conclude that while the proposed price-cap rule guarantees declining rates in real terms, it is unclear that rates will be, *at all times*, lower than what they would be under rate-of-return regulation. However, since price-cap regulation would promote a more efficient investment in cost reduction, it is possible, if not likely, that consumers would prefer the change of regime. In fact, since the regulator is able to set both P_0 and x, there is no reason why there should be any conflict between efficiency and equity. As we saw earlier in the article, x influences the firm's investment in cost reduction, while P_0 does not. Therefore, the regulator should choose x so as to maximize efficiency, and use P_0 as an instrument to divide the efficiency gains between the firm and consumers.

In general, consumer welfare is increased by setting the initial price cap somewhat below current cost. This guarantees to consumers a period of lower prices without compromising the firm's incentives for cost reduction. At its best, price-cap regulation promotes cost reduction by promising the firm an ex post rent from its investment. Setting the initial price cap below cost is a way to redistribute that rent to consumers ex ante.

5. Conclusion

We have argued that price-cap regulation promotes incentives for investments in cost reduction, compared to cost-of-service regulation, provided that future price caps are not too low. On the other hand, a price cap that declines too precipitously might destroy investment incentives altogether. Moreover, even a price cap that successfully promotes cost reduction does not necessarily guarantee consumers lower prices in the future. Regulators should consider initially setting the price cap below current cost as a method for redistributing the benefits of price-cap regulation to consumers.

There are various issues relating to price-cap regulation which our analysis did not address, including regulation of a dominant firm, incentives for quality improvement, and information asymmetries.[7] However, we would expect the main results of our stylized model to hold in more general contexts.

Appendix

Proof of Proposition 2.1.

If $x = P_0$, then the benefits from cost reduction are zero, and so $e^*(x) = 0$. Since demand and C_e are bounded, this is also true for values of x close to P_0.

Q.E.D.

The following mathematical lemma is well known.

Lemma A.1. Consider a twice differentiable function $f(x,y), f\colon \Re^2 \to \Re$. Suppose $z(y) = \arg\max_x f(x,y)$. Then,

$$\text{sign}\left(\frac{dz}{dy}\right) = \text{sign}\left(\frac{\partial^2 f}{\partial x\, \partial y}\right) \tag{A1}$$

Proof of Proposition 2.2.

If the price cap is binding, then $\pi = [P_0 - x - C(e)]\, D(P_0 - x) - e$, and by (A1),

$$\text{sign}\left(\frac{de*}{dx}\right) = \text{sign}\left(\frac{\partial^2 \pi}{\partial e\, \partial x}\right) = \text{sign}\left(\frac{dC}{de}\frac{dD}{dB}\right) \tag{A2}$$

which is positive, given the assumptions previously made. Q.E.D.

Proof of Proposition 3.1.

Denote by $M(c)$ the unconstrained monopoly price. The firm's expected profit is given by

$$\begin{aligned}&\int_0^{M^{-1}(P_0 - x)} (M(c) - c)\, D(M(c))\, dF(c \mid e)\\ &+ \int_{M^{-1}(P_0 - x)}^{P_0 - x} (P_0 - x - c)\, D(P_0 - x)\, dF(c \mid e)\end{aligned} \tag{A3}$$

The derivative with respect to x is given by

$$\begin{aligned}\frac{\partial \Pi}{\partial x} &= -\int_{M^{-1}(P_0 - x)}^{P_0 - x} (P_0 - x - c)\frac{\partial D}{\partial x} + D(P_0 - x)\, dF(c \mid e)\\ &= -\int_{M^{-1}(P_0 - x)}^{P_0 - x} (M^{-1}(P_0 - x) - c)\frac{\partial D}{\partial x}\, dF(c \mid e),\end{aligned} \tag{A4}$$

for $D(p) + (p - M^{-1}(c))\dfrac{\partial D}{\partial p} = 0$. Finally,

$$\frac{\partial^2 \Pi}{\partial x\, \partial e} = -\frac{\partial}{\partial e}\int_{M^{-1}(P_0 - x)}^{P_0 - x} (M^{-1}(P_0 - x) - c)\frac{\partial D}{\partial x}\, dF(c \mid e). \tag{A5}$$

Given that F_e is positive, $e'' > e'$ implies that $F(c \mid e')$ dominates $F(c \mid e'')$ in the sense of first-order stochastic dominance. Therefore, since the integrand is an increasing function of c, the right-hand-side of (A5) is positive (cf., Milgrom, 1981). Finally, the result follows from Lemma A.1. Q.E.D.

Proof of Proposition 3.2

Suppose that $x = P^0 - \varepsilon$. For a small enough ε, expected benefits from cost reduction are given by $\int_0^{\varepsilon} (\varepsilon - c)\, D(\varepsilon)\, dF(c \mid e)$. Since dF is bounded, both expected benefits and the derivative of expected benefits with respect to e converge uniformly to zero with ε. Therefore, there exists a small enough ε such that the derivative of expected benefits with respect to e is less than one, and the optimal solution is $e = 0$.

Q.E.D.

Proof of Proposition 4.1

Since we assume marginal cost to be constant after Δ, the rate of profit is constant during the period $[\Delta, \Delta + \delta]$, and total benefit under price-cap regulation is proportional to δ. The result follows from the Arrow effect, just as in Proposition 2.2.

Q.E.D.

Notes

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1. For an analysis of the dominant firm case, see Cabral (1988).
2. Alternatively, one can make the assumption that at time T regulation reverts to a regime of cost-based regulation without regulatory lag.
3. The rate of profit is integrated over the period $[\Delta, T]$. Since profit is constant, (2) is obtained by an appropriate change in units.
4. If the price cap is not binding, then the level of investment is invariant with respect to x.
5. Formally, increased effort reduces cost in the sense of first-order stochastic dominance. See Milgrom (1981).
6. It can be shown that the derivative of monopoly price with respect to marginal cost is less than one (one half, in the case of linear demand).
7. Some of these issues are covered in Baron (1988) and Cabral (1988).

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