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Can Regulation Increase Firm's Efficiency?*

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Abstract

This paper examines the possibility that regulation actually increases a monopolist's cost-efficiency. When the firm's cost-reducing effort depends on the output supplied, a binding price-cap, by compelling the monopolist to produce more, finally results in lower costs. On the basis of a two-period asymmetric information model with a repeated choice of effort, the paper demonstrates that regulation increases efficiency when the elasticity of demand is sufficiently low, even assuming very conservative preferences and a very poor information set for the regulator. Moreover, contrary to previous findings and conventional wisdom, we find that a periodical rate base review exerts also a positive effect on future cost-reducing effort countervailing the well known ratchet effect.

JEL Code: L 51, D42

Keywords : Price-cap, regulatory lag.

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1. Introduction[*]

Notwithstanding the huge amount of work that economists have devoted to the study of natural monopoly regulation, the theoretical literature on the properties of currently applied price regulation schemes remains still surprisingly scant. Most of the work has been accomplished in the area of optimal price regulation. A wave of theoretical works about price-cap regulation dates back to its first time implementation in the UK in the second half of the 80s. In particular in the Introduction to a Symposium on price-cap regulation in the RAND Journal of Economics in 1989, Acton and Vogelsang noted that:

> "The theoretical and applied analysis of the desirability, performance and practical implementation of price-caps has made substantial recent progress. […] Most of this work is highly stylized in its assumptions and therefore not readily applicable. This calls for more theoretical work under different assumptions".

Unfortunately, during the last decade the amount of work in this area has been somewhat disappointing when compared with the practical relevance[1] of the issue (see Crew-Kleindorfer 2002 and Bertoletti 2002).

Therefore the state of the art is largely determined by those seminal contributions. In particular, the original proposal of the Littlechild Report (1983), that claimed the superiority of price-caps from several points of view, has been reinforced by several subsequent studies. In particular, price-caps were deemed to be less burdensome from the information and administrative point of view, to allow more flexibility in relative pricing, and to provide more incentive to innovation. Cabral and Riordan (1989) provide theoretical support to the claim that price-cap regulation is more effective in inducing a higher level of investment in cost reduction. Braeutigam and Panzar (1989) suggest that price-caps may perform better than ROR when the regulated firm is also allowed to compete in some unregulated markets, due to its lower information burden especially on cost allocation. Sibley (1989) claims that price-caps, combined with an appropriate

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[1] In the meantime price-cap schemes have been extensively applied in most developed countries (for the Italian experience, see OCDE 2001 and De Vincenti 2002).

transfer of the ISS type based on lagged profits and incremental consumer surplus, induce cost minimizing behaviour and severely limit rents from private cost information. Bradley and Price (1988) and Vogelsang (1989) provide arguments in favour of the thesis that global price-caps weighted by lagged quantities may approximate the Ramsey price structure in the long run.

Part of the initial optimism about the properties of price-cap regulation has been subsequently proved excessive. In particular, the idea that price-caps could be implemented without evaluating cost levels clashes with the practical need to find a reasonable basis to ensure financial sustainability of service provision (Armstrong-Cowan-Vickers, 1994 and Cavallo-Coco, 2002). Furthermore Cowan (1997) and Armstrong and Vickers (1991 and 2000) showed that global caps are not immune, particularly in the form of average revenue caps, from distortions in the structure of relative prices. Therefore the price-cap information and administrative burdens proved to be less negligible than previously hoped. Several contributions (for instance Gilbert-Newbery 1994) also contended that price-caps may induce an inefficient level of investment compared to ROR regulation, although Biglaiser-Riordan (2000) showed that under the assumption of exogenous technological progress the opposite is true. Moreover, the need for periodical reviews implies the possibility of strategic behaviour of the firm of the type highlighted in the literature on the "ratchet effect" (see for instance Milgrom-Roberts 1992, ch. 7, and Laffont-Tirole 1993, ch. 9).[2] In truth, the need to tackle the issue of the frequency of the change in the base of the price-cap was already signalled by Acton and Vogelsang (1989) as one of the main implementation issues on which to focus attention in forthcoming research.

The purpose of this paper is to follow the call by Acton and Vogelsang for more theoretical work on the properties of price-caps, with the limited, but still ambitious aim of improving the way regulation is actually implemented. In particular, this work focuses on some issues concerning price (and particularly price-cap) regulation that are often considered as settled in the academic literature: the incentive effects on productive efficiency of fixed price schemes and rate base reviews.

[2] The general problem of ratcheting has been firstly highlighted in the context of centrally planned economies. Production targets fixed on the basis of past performance induced productive inefficiencies due to the anticipation by the Soviet-type firm of target revisions by the planners (see Gindin, 1970 and Weitzman, 1980). For a different point of view, which also emphasises a "push effect" of the target review on effort that is obtained assuming a satisfying behaviour, see De Vincenti (1984).

It is usually contended that price regulation reduces incentives to productive efficiency. In relative terms, price-cap schemes are deemed to perform better than other regulatory schemes because they preserve incentives to effort and to choice of the optimal capital/labour ratio. This paper puts forward an argument for believing that, under certain conditions, price-cap regulation may actually improve monopolist productive efficiency. There may be several reasons for which an unregulated monopolist or a firm regulated by non-binding caps may lower its cost-reducing effort below the socially optimal level. For example, insufficient market discipline could originate phenomena similar to those correlated with soft budget constraints, when there is separation between management and property of the firm and when the management maximises its discretionary budget with a profit constraint[3]. This paper concentrates on another, simpler, reason. We build on the so-called "Arrow effect": comparing the incentives to process innovation under a monopolistic and a competitive market structure, Arrow (1962) concluded that they are greater under competition because the marginal gain from innovation in terms of cost-reduction is positively correlated with output. Cabral and Riordan (1989) exploited this intuition in a natural monopoly regulation model to highlight the positive, but discontinuous relationship between the X parameter of the price-cap and the level of a one-shot effort exerted by the firm at the beginning of the regulatory period[4].

We develop this idea in a two-period natural monopoly model characterised by repeated choice of the effort by the firm and by asymmetric information between regulator and firm. Firstly, we obtain in our setting a result similar to Cabral and Riordan: whenever the regulated price is binding for the monopolist in both periods, then effort supplied by a regulated firm must also be larger than the monopolist effort. A regulated monopoly may be more cost-efficient than an unregulated one, so that regulation may not only improve allocative efficiency but also productive efficiency. Starting from this basic result, we proceed finding minimal conditions under which price-cap regulation strictly increases productive efficiency even assuming for the regulator very conservative preferences and a very poor information set. These conditions ultimately refer to the monopoly power of the firm - that is to the elasticity of demand - and to the shape of its

[3] For a comparison of the performance of firms in a competitive and a monopolistic market structure under these hypotheses, see Hart (1983).

[4] Clementz (1991) extends the result in Cabral and Riordan by demonstrating that price-cap is superior to rate-of-return not only in delivering more innovation but also in delivering a higher level of overall social welfare.

effort disutility function. Our conditions are minimal in the sense that any different assumption about the regulator preferences and its information set allows a more binding cap and therefore the effect of price regulation on cost-efficiency is reinforced.

A second focus of the paper is on the relative merits of purely fixed price schemes and periodical rate base reviews, or, in other terms, on the problem of the optimal length of the regulatory period. The received wisdom on this topic runs like this: revising the base for the new regulatory period reduces incentives to cost-reduction because of the ratchet effect; on the other side a revision is necessary to redistribute gains from cost-reduction to consumers and to achieve allocative efficiency. Thus the longer the regulatory lag the better the incentive properties and the worse the distributive and allocative properties of the regulatory scheme (see for example Armstrong and Sappington, 2002, Armstrong, Rees and Vickers, 1995). From this tension between conflicting objectives of the regulator, there arises an optimal regulatory lag. This story overlooks a very basic and practical worry of regulators in setting and re-setting the X: its incentive properties. Long regulatory lags may result in a wide divergence between costs and prices, that in turn may cause adverse consequences on the firm's productive efficiency as illustrated above through the effects of monopoly pricing on effort. Indeed, as we will show, a periodical revision of the rate base which reduces the divergence between prices and costs may induce the firm to supply more effort in the future, so that it may be useful not only on allocative or distributive grounds, but also on purely productive efficiency grounds. This result strikingly contrasts also with findings in Cabral and Riordan (1989) and in Clementz (1991), whose model is unable to account for further incentive effects of a rate base review because of the one-shot effort hypothesis. Of course, in setting the regulatory lag, the regulator has to balance these positive effects of the rate base review on the future levels of effort with the well known adverse consequences on the current level of effort arising from the ratchet effect.

Both our results in general contrast sharply with conventional views and particularly with a recent contribution by Lewis and Yildirim (2002). In line with previous findings the authors find that cost-reducing '*innovation is encouraged by light handed regulation*' and that it '*is more rapid in a durable franchise*'. Otherwise, in the terminology adopted here, they find that it may be necessary to leave the firm with a large information rent in order to stimulate innovation and that from the perspective of productive efficiency, long regulatory periods are always preferable. Our results are opposite to these. We find that tight price-cap

regulation increases efficiency even relative to the unregulated monopolist benchmark. Moreover, due to the necessary divergence between price and cost arising from asymmetric information, we find that a review of the rate base may be useful to increase productive efficiency. The different conclusions arise from two main differences in our model. Firstly, Lewis and Yildirim describe a framework in which a regulator awards a franchise contract specifying both an amount of service and a corresponding payment. Examples of this type of regulatory framework are quite common (for example the Public Service Contract of the Italian Railways). However the most common form of regulation is by far price regulation (by RoR or price-cap), in which the amount of service delivered is determined by the demand side in the market. This is our case. Secondly, they assume that innovation is purely generated by learning by doing. No cost is borne by the firm. We prefer the assumption that innovation and, more generally, cost efficiency require effort or some sort of non-monetary cost on the side of the firm.

2. Prices and incentives

In this section we will highlight the dependence of the choice of effort by the monopolist firm on the level of price. We will start with the simplest possible model in order to focus on the issue. We assume a single-product firm with a production function characterised by constant returns to scale for any given level of its effort and by a permanent effect of effort on the unit cost. In this sense the model best describes a situation in which a manager has to decide whether to invest on the upgrading of productive processes. Once the investment has been made the costs are permanently lower.[5] Here we assume a one-shot effort in the first period: the marginal costs in every period are dependent on the effort spent in the first period, that is $c_t = c(e_0)$ for $\forall\, t = 0,1,2,\ldots$, with $c'<0$, $c''>0$. The model contemplates an infinite number of periods. The firm is supposed to be risk neutral and to maximise profits, net of the disutility which derives from supplying cost-reducing effort, $\varphi(e)$, with the disutility of effort being increasing and convex: $\varphi'(e)>0$ and $\varphi''(e)>0$; $\varphi(0)=0$ and $\varphi(1)=\infty$.[6] The effort spent is strictly sector-

[5] A similar hypothesis about the effects of effort on costs is used by Boitani-Cambini (2002) in building a menu of subsidy contracts for regulated firms which are burdened with public service obligations.

[6] An example of a functional form characterised by these properties is $\varphi(e) = \frac{k}{1-e} - k$, where k is a constant.

specific and hence its disutility is a sunk cost for the firm. The firm then maximizes:

$$U = \sum_{t=0}^{\infty} \delta^t \left[p_t y(p_t) - c(e_0) y(p_t) \right] - \varphi(e_0) \qquad [1]$$

where δ is the one-period discount factor and subscripts denote the periods. Suppose that demand function $y(p)$ is constant over time. Profit maximisation entails the choice of effort and, if unregulated, prices in all periods. In order to focus on the relationship between effort levels and prices, we will isolate the choice of the effort given the level of price *p** in all periods (a profit maximising price for an unregulated monopolist firm or an exogenously fixed price for a regulated firm). The FOC for the choice of effort is:

$$U_{e_0} = -\frac{1}{r\delta}(c'y) - \varphi' = 0 \qquad [2]$$

where *r* is the rate of interest. Under the standard assumptions above the SOC is satisfied. A simple exercise in comparative statics allows us to compute the following derivative:

$$\frac{de_0}{dp^*} = -\frac{U_{ep}}{U_{ee}} = -\frac{-c'y'}{-c''y - r\delta\varphi''} < 0 \qquad [3]$$

This implies that lower prices exert a beneficial effect on incentives to cost reduction. The intuition for this is that if effort reduces marginal cost then the benefit of supplying effort for the firm will be larger the more output it produces ("Arrow effect").

3. Regulation and incentives

In this section we will demonstrate that because of the effect highlighted in section 2, it is possible that a regulated monopolist is more cost-efficient than an unregulated one even in the case of very sharp asymmetry in information between regulator and firm. In particular, we will find the minimal conditions under which the price fixed by the regulator is binding for the firm (i.e. lower than monopolist prices). For the result above, this implicitly increases incentives to supply effort and finally productive efficiency. Therefore, price-cap regulation not only, as usually stated, preserves private monopolist incentives to productive efficiency[7]

[7] Leaving aside for the moment considerations related to the relevance of ratchet effect.

but it may actually induce a monopolist to supply higher levels of effort even when the regulator is equipped with a very poor information set.

We will build on a very simple two-period model (that is $t = 0,1$) to focus on the issue, bearing in mind that it can be generalized to an *n*-period setting without affecting the conclusions reached. In this model, effort again has a permanent effect on costs, but the manager/entrepreneur can further decrease costs by spending effort e_1 in the second period too. Assuming a simplified form for the relationship between cost and effort, that is $c_t = c_{t-1}(1-e_t)$, the firm's intertemporal utility is:

$$U = p_0 y(p_0) - c_{-1}(1-e_0)y(p_0) - \varphi(e_0) + \delta[p_1 y(p_1) - c_{-1}(1-e_0)(1-e_1)y(p_1) - \varphi(e_1)] \quad [4]$$

Of course, given the functional form chosen for costs, it must be $0 \le e_t < 1$, consistently with the assumptions on $\varphi(e)$. Suppose also for simplicity that δ, the discount factor, is 1. Utility maximisation for the monopolist entails:

$$U_{e_0} = c_{-1} y(p_0 *) - \varphi'(e_0) + [c_{-1}(1-e_1)y(p_1 *)] = 0 \quad [5]$$

$$U_{e_1} = [c_{-1}(1-e_0)y(p_1 *)] - \varphi'(e_1) = 0 \quad [5']$$

and, as in the previous case, comparative statics confirms that effort levels depend negatively on the level of prices:

$$\frac{de_0 *}{dp_0 *} = -\frac{U_{e_0 p_0}}{U_{e_0 e_0}} = \frac{c_{-1} y_0'}{\varphi''(e_0)} < 0 \quad [6]$$

$$\frac{de_0 *}{dp_1 *} = -\frac{U_{e_0 p_1}}{U_{e_0 e_0}} = \frac{c_{-1}(1-e_1) y_1'}{\varphi''(e_0)} < 0 \quad [6']$$

$$\frac{de_1 *}{dp_1 *} = -\frac{U_{e_1 p_1}}{U_{e_1 e_1}} = \frac{c_{-1}(1-e_0) y_1'}{\varphi''(e_1)} < 0 \quad [6'']$$

It follows that if regulation prevents monopoly pricing, then it must also increase productive efficiency. In particular costs must be lower under regulation.

3.1. Symmetric Information

To start with, suppose there is symmetric information between regulator and firm about costs and the disutility of effort (from now on we will assume that the demand function is common knowledge). Then a benevolent regulator fixes prices

(output) by simply maximising consumer welfare under the firm's participation constraint:

$$\max \int p_0 dy_0 + \int p_1 dy_1$$

$$\text{sub } U \geq 0 \qquad [7]$$

where we are assuming that the regulator is not allowed to use transfers and we maintain the hypothesis $\delta = 1$ for simplicity.

Proposition 1. Under symmetric information, a regulated monopolist always exerts more effort and consequently produces at lower costs than an unregulated one.

Proof. Due to the fact that the choice of effort is in practice delegated to the firm, conditions [5] and [5'] are valid just like in the unregulated monopolist case. Note that these conditions entail that the level of effort chosen is in practice a function of the level of output (prices). Conditions for the choice of output are instead:

$$p_0 = \lambda\left[p_0 + y_0 p_0' - c_{-1}(1-e_0)\right] = \lambda\left[MR_0 - MC_0\right] \qquad [8]$$

$$p_1 = \lambda\left[p_1 + y_1 p_1' - c_{-1}(1-e_0)(1-e_1)\right] = \lambda\left[MR_1 - MC_1\right] \qquad [8']$$

where λ is the (negative) Lagrange multiplier, MR_t and MC_t are respectively the marginal revenue and marginal cost in period t. For any meaningful (positive) price, conditions [8] and [8'] require prices such that $MR<MC$ in both periods. Hence prices are lower than the monopolist's (in particular, prices are fixed by the regulator where the participation constraint binds). Combining this information with conditions [5] and [5'], Proposition 1 follows immediately. Q.E.D.

The intuition for the result is fairly simple. If unregulated, the monopolist would exploit the market in the standard way by limiting production. However, the incentive to spend effort depends on the amount of production. Therefore limiting the monopolist's pricing power through regulation also increases the incentive to spend effort and finally increases productive efficiency. Regulation thus is beneficial not only on allocative and distributive grounds, but also on a pure internal efficiency perspective.

Of course, such a neat result wouldn't be thinkable in a more realistic set. In the remainder of the paper we will describe how the effect works in more complex environments.

3.2. Asymmetric information

In this paragraph we will assume a simplified asymmetric information context: the regulator does not know the function $\varphi(e)$; moreover, it cannot observe the monopolist's current effort and cost, but it is perfectly informed about past costs; for simplicity we assume that costs are not subject to any stochastic shock, so that marginal cost at time *t* can only be equal to, or lower than, the marginal cost at time *t*-1. Suppose also that the regulator can credibly commit itself to an *ex ante* specified pricing pattern for both periods, thanks to the legislative framework and to its reputation. In particular, the regulator commits itself to a constant price over time.

In this case our aim is to deliver conditions under which, by exploiting only past information, the regulator is able to improve firm's efficiency. We add an additional and final constraint to the model set out above: the regulator is supposed to be mainly interested in continuity of service.[8] We will model this feature by assuming infinite risk aversion on the side of the regulator. This considerably simplifies the interaction between the regulator and the firm: the regulator sets the price in such a way as to be certain that the participation constraint is satisfied. Hence in the model, it will set prices in both periods at past cost, and $p_0^* = p_1^* = c_{-1}$, where the star denotes that prices have been capped at that level.

Proposition 2. Under asymmetric information, the monopolist exerts a greater effort when regulated if the elasticity of demand is sufficiently low.

Proof. The monopolist chooses effort according to conditions [5] and [5']. Therefore, the effort of the regulated monopolist is higher than that of the

[8] Contrary to the modern approach to natural monopoly, Farrer (1902, cit. in Newbery, 1999) lists the fact that it produces "necessities or essential for the community" among its typical features. Although there may be doubts about the most rigorous definition, it is still a fact that most natural monopolies are public services. Continuity of services is therefore tantamount for the community and, consequently, for the regulator.

unregulated one if monopoly prices in both periods are higher than the regulated ones. Monopoly prices in the two periods can be easily obtained by differentiating the utility function [4] with respect to quantities. It follows that FOC conditions on prices can be written:

$$\frac{\varepsilon_0}{\varepsilon_0 - 1} c_{-1}(1 - e_0) > c_{-1} \quad \text{and} \quad \frac{\varepsilon_1}{\varepsilon_1 - 1} c_{-1}(1 - e_0)(1 - e_1) > c_{-1} \qquad [9]$$

where ε and e are respectively the elasticity of the demand curve and the effort level at the optimum of the unregulated monopolist. Conditions [9] are satisfied respectively when:

$$\varepsilon_0 < \frac{1}{e_0} \quad \text{and} \quad \varepsilon_1 < \frac{1}{e_0 + e_1 - e_0 e_1} \qquad [10]$$

A low value for ε, hence a high monopoly power, implies that the regulated price $p_0^* = p_1^* = c_{-1}$ is binding and that it induces a higher effort compared to that chosen by an unregulated monopolist. Q.E.D.

In conclusion, even an infinitely risk-averse regulator equipped only with a very poor information set can induce the monopolist to exert a higher level of effort than the one provided in absence of regulation. Therefore, it can improve not only allocative but also productive efficiency. This result is subject to a simple condition, ultimately referable to the monopoly power of the firm. Any different assumption about the regulator preferences and its information set allows a more binding cap and therefore the effect of price regulation on cost-efficiency is reinforced.

Note that the second of conditions [10] is necessarily more binding than the first one. Let us suppose that the first of conditions [10] is satisfied but the second is not: even in this case, regulation can improve productive efficiency because it increases the effort in the first period, leading to a permanent reduction in costs.

Proposition 3. Even if the cap $p_0^* = p_1^* = c_{-1}$ is binding for the monopolist only in the first period, regulation can still improve cost efficiency in both periods.

Proof: Suppose that the first of conditions [9] (or equivalently [10]) holds but not the second. In this case we know that a price-cap at the level c_{-1} is binding in the first period but not in the second, so that the price in the second period is

chosen by the firm below the threshold c_{-1} set by the regulator. Differentiating the firm's utility function with respect to the choice variables e_0, e_1 and y_1, we obtain a system of FOCs constituted by equations [5], [5'] and:

$$U_{y_1} = p_1 + p_1' y_1 - c_{-1}(1-e_0)(1-e_1) = 0 \qquad [5'']$$

Let us use these FOCs to obtain the derivatives of the choice variables with respect to the regulator's policy instrument, that is p_0:

$$\begin{bmatrix} \frac{de_0^*}{dp_0} \\ \frac{de_1^*}{dp_0} \\ \frac{dy_1^*}{dp_0} \end{bmatrix} = \mathbf{H}^{-1} \cdot \begin{bmatrix} -\frac{dU_{e_0}}{dp_0} \\ -\frac{dU_{e_1}}{dp_0} \\ -\frac{dU_{y_1}}{dp_0} \end{bmatrix} \qquad [11]$$

where **H** is the Hessian matrix of the monopolist's choice problem. Taking into account that $-(dU_{e_0}/dp_0) = -c_{-1} \cdot y'(p_0) > 0$, that the sign of the determinant of **H** is negative because of the SOCs, and that the second and the third element in the vector on the right hand side of the system [11] are zero, the signs of the derivatives of the choice variables inversely depend on the signs of the elements in the first row of the adjoint matrix. Hence:

$$sign\left(\frac{de_0^*}{dp_0}\right) = sign\left\{-\left[-\varphi''(e_1)\cdot(2p_1' + p_1'' y_1) - c_{-1}^2(1-e_0)^2\right]\right\} \qquad [12]$$

$$sign\left(\frac{de_1^*}{dp_0}\right) = sign\left\{-\left[c_{-1} y_1 \cdot (2p_1' + p_1'' y_1) + c_{-1}^2(1-e_0)(1-e_1)\right]\right\} \qquad [12']$$

$$sign\left(\frac{dy_1^*}{dp_0}\right) = sign\left\{-\left[\varphi''(e_1)\cdot c_{-1}(1-e_1) - c_{-1}^2 \cdot y_1(1-e_0)\right]\right\} \qquad [12'']$$

The term in the square brackets in equation [12] is the determinant of the Hessian matrix of the reduced maximisation problem of the monopolist in the second period. As such, it must be positive for second order conditions and the sign of the derivative de_0^*/dp_0 has to be negative as expected: a price-cap binding in the first period increases the current level of effort.

The sign of the term in the square brackets in equation [12'] is *a priori* uncertain, so that the sign of de_1^*/dp_0 is also uncertain. It is of particular interest that, under the condition $\left| y_1 \cdot \frac{d^2R/dy_1^2}{dR/dy_1} \right| < 1$ (where R is the revenue function in period 1), even this derivative is negative and a price-cap binding only in the first

period increases the effort in the second period as well. In this case it follows trivially that the marginal cost in the second period is lower than in an unregulated monopoly case.

Yet the marginal cost in the second period may still be lower under regulation even when the condition above is not satisfied and $de_1^* / dp_0 > 0$. Taking account of the FOC [5'], the term in square brackets in equation [12''] becomes $\varphi''(e_1) \cdot c_{-1}(1-e_1) - c_{-1}\varphi'(e_1)$ which is positive, so that $dy_1^* / dp_0 < 0$, when:

$$\frac{\varphi''(e_1)}{\varphi'(e_1)} > \frac{1}{1-e_1} \qquad [13]$$

Therefore, if condition [13] holds, a price-cap which is binding only in the first period implies a higher output in the second period, that is a necessarily lower marginal cost not only in the first but also in the second period. Q.E.D.

Condition [13] can be interpreted as requiring a sufficient degree of convexity of the disutility function $\varphi(e)$. In particular the index $\frac{\varphi''(e_1)}{\varphi'(e_1)}$ can be labelled as the degree of aversion to variability of effort, in analogy with the absolute degree of risk aversion. Indeed when the index is sufficiently large, the monopolist bears remarkable costs for supplying different levels of effort in the two periods. Note that, for the functional form suggested in footnote 3, we obtain $\frac{\varphi''(e_1)}{\varphi'(e_1)} > \frac{2}{1-e_1}$ so that condition [13] is satisfied.

In conclusion, even when the cap imposed by the regulator is binding in the first period while in the second one the monopoly price is lower than the cap, marginal costs are lower in both periods with respect to those of an unregulated monopolist because of the increase in the effort obtained in the first period. Therefore, even if the cap is not binding in the second period, the price p_1 chosen by the monopolist in this period has to be lower than in the case the monopolist had not been regulated at all. This result is subject to a simple condition, ultimately referable to the convexity of the effort disutility function.

3.3. Effects of rate base review on efficiency

Conventional wisdom, confirmed by recent theoretical research (Armstrong and Sappington, 2002 and Lewis and Yildirim, 2002), states that productive

efficiency and innovation are always encouraged by long regulatory lags and light regulation, in the form of some information rent for the firm. The objective of this section is to show that this is not necessarily the case. In the particular context of our simplified model, we want to devise conditions under which the regulator prefers to revise the rate base in the second period in order to take account of the costs it observes at the end of the first period. Note that here we are focussing on conditions for the rate base review to exert a positive effect on productive efficiency only. In order to do this we will compare the relative virtues of a purely fixed price approach and a rate base review approach. Indeed the relationship between price and effort, previously referred to as "Arrow effect", implies that a downward adjustment of the regulated price in the second period increases effort in the same period. Of course, if the firm anticipates that its cost-reducing effort in period 0 affects the adjustment of price in period 1, it will reduce the effort at time 0. This is the well known ratchet effect. Our question is then: When does the first effect overcome the second and a rate base review reducing the firm's rent is desirable for productive efficiency too?

We will analyse this topic assuming a rational expectations hypothesis for the firm, that is it anticipates the regulator's choice about the cap in the second period. Moreover, we will keep the assumption that the regulator can commit itself to the fixed price contract thanks to the legislative framework and to its reputation. Therefore, the regulator will adopt a pure fixed price approach or a rate base review approach depending on the comparison between their relative merits from a productive efficiency point of view. We will analyse these relative merits with respect to the marginal cost at the end of the regulatory period, that is, we will find the condition under which the base review will deliver a lower cost c_1.

The monopolist will maximise the utility function [4] – where, for simplicity, we continue to suppose $\delta=1$[9] - taking the adjustment of the regulated price in the second period into account, that is, it knows that $p_0=c_{-1}$ and

$$p_1 = c_{-1}(1-\lambda e_0)$$

where $0\leq\lambda\leq1$, is the parameter of adjustment of prices to realized cost. When $\lambda=0$ there is no adjustment and the regulatory scheme is a pure fixed price one. When $\lambda=1$ adjustment is complete and realized productivity gains are entirely reflected in lower prices. As stated above we will focus on efficiency in the final period as

[9] Note that this hypothesis maximises the ratchet effect. A lower discount factor would reduce the negative impact of the ratchet effect on productive efficiency when a rate base review occurs, hence enlarging the set of parameters for which the review is preferred by the regulator.

summarised by the firm's marginal cost, $c_1=c_{-1}(1-e_0)(1-e_1)$. To determine whether it may be efficient at all for the regulator to review the base at the end of period 0, we will look at the derivative $dc_1/d\lambda$, at $\lambda=0$. When the derivative is negative then a review of the rate base is efficient.

Proposition 4: A rate base review in the second period is desirable even on purely productive efficiency grounds when the elasticity of demand is sufficiently large.

Proof: The above mentioned condition on the derivative:

$$\left.\frac{dc_1}{d\lambda}\right|_{\lambda=0} = \left[-c_{-1}(1-e_1)\frac{de_0}{d\lambda} - c_{-1}(1-e_0)\frac{de_1}{d\lambda} \right]_{\lambda=0} < 0$$

implies that a rate base review is efficient when $\left.\frac{de_1}{d\lambda}\right|_{\lambda=0} > -\frac{(1-e_1)}{(1-e_0)}\left.\frac{de_0}{d\lambda}\right|_{\lambda=0}$. Taking into account that e_0, e_1 are small compared to 1, and assuming that $e_0 \approx e_1$[10], the condition can be simplified to $\left.\frac{de_1}{d\lambda}\right|_{\lambda=0} > -\left.\frac{de_0}{d\lambda}\right|_{\lambda=0}$.

In order to find the meaning of this condition in our model, we differentiated the utility function with respect to the effort levels in the two periods to obtain the following first order conditions:

$$U_{e_0} = c_{-1}y_0 - \varphi'(e_0) - c_{-1}y_1(.)[\lambda - (1-e_1)] + \\ - \lambda c_{-1}^2 y_1'(.)[(1-\lambda e_0) - (1-e_0)(1-e_1)] = 0 \qquad [14]$$

$$U_{e_1} = c_{-1}(1-e_0)y(.) - \varphi'(e_1) = 0 \qquad [14']$$

Condition [14'] for the optimal effort in the second period is equal to condition [5']. Therefore, the effort in period 1 is higher when a rate base review occurs because of the downward adjustment of price. On the other hand, the presence of the adjustment parameter λ in the first equation necessarily implies a lower effort in period 1 due to the ratchet effect. Global effects on e_0 and e_1, can be found with a simple comparative statics exercise on the system of equations [14] and [14'][11]:

[10] This hypothesis plays a simplifying role in the following analysis. Note, however, that it is consistent with condition [13] about the monopolist's aversion to variability of effort.

[11] All derivatives here are evaluated at $\lambda=0$.

$$\begin{bmatrix} \frac{de_0}{d\lambda} \\ \frac{de_1}{d\lambda} \end{bmatrix} = \begin{bmatrix} U_{e_0e_0} & U_{e_0e_1} \\ U_{e_1e_0} & U_{e_1e_1} \end{bmatrix}^{-1} \begin{bmatrix} -U_{e_0\lambda} \\ -U_{e_1\lambda} \end{bmatrix} \qquad [15]$$

All the elements on the right side of the equation have determined sign except for $U_{e_0\lambda} = -c_{-1}y_1 - c_{-1}^2 y_1'(.)[2e_0 + e_1 - 2e_0e_1]$, that depends on the values of parameters. Note however that this element synthesises the ratchet effect. As such, it is reasonable to assume that its sign be negative, given that when future prices track more closely present cost (higher λ) the incentive to supply effort must be lower.

From the system [15] it follows that the condition $\frac{de_1}{d\lambda} > -\frac{de_0}{d\lambda}$ can be written:

$$\frac{\left[U_{e_0e_1}U_{e_0\lambda} - U_{e_0e_0}U_{e_1\lambda}\right] + \left[U_{e_0e_1}U_{e_1\lambda} - U_{e_1e_1}U_{e_0\lambda}\right]}{|H|} > 0 \qquad [16]$$

where $|H|$, the determinant of the Hessian matrix of the optimisation problem, is positive for SOC. Assuming as before that $e_0 \approx e_1$, then $U_{e_0e_0} = -\varphi''(e_0) \approx -\varphi''(e_1) = U_{e_1e_1}$, and this condition can be restated as follows:

$$\left[U_{e_0e_1} - U_{e_0e_0}\right]\left[U_{e_0\lambda} + U_{e_1\lambda}\right] > 0 \qquad [16']$$

From SOC it also follows that the term in the first parenthesis is positive, and therefore the whole condition holds when the second square parenthesis is positive. That is when:

$$\varepsilon_1 > \frac{1}{e_0(3 - 2e_1 - e_0) + e_1} \qquad [17]$$

where ε_1 is the elasticity of demand at $p_1 = c_{-1}$. A minimum level of elasticity is then the condition required to ensure that a $\lambda > 0$, and therefore a review of the rate base, is optimal for productive efficiency. Q.E.D.

The intuition for this result is fairly straightforward. When the elasticity is large a tightening of the price-cap in the second period produces large increases in output leading to large productivity gains in the second period through the "Arrow effect".

The right side of condition [17] is lower than the right side of both conditions [10], so that the regulator may face alternative situations. Regulation is never beneficial if the first of conditions [10] is not satisfied, that is for high values of the elasticity of demand. If that condition is satisfied, the following more interesting cases can arise under the usual hypothesis of $d\varepsilon/dy \leq 0$.

a) If the elasticity ε_1 at the monopoly price satisfies the second of conditions [10], then a rate base review is desirable depending on the value of the elasticity of demand at $p_1=c_{-1}$:
   - for $\varepsilon_1 < \frac{1}{e_0(3-2e_1-e_0)+e_1}$, the fixed price $p_1=c_{-1}$ is so binding in the second period that the rate base review worsens overall productive efficiency;
   - for $\varepsilon_1 > \frac{1}{e_0(3-2e_1-e_0)+e_1}$, the fixed price $p_1=c_{-1}$ is binding in the second period, but a partial rate base review can further improve productive efficiency thus inducing a larger reduction in the marginal cost c_1.

b) If the elasticity ε_1 at the monopoly price does not satisfy the second of conditions [10], so that $p_1=c_{-1}$ is not binding, then also $\varepsilon_1 > \frac{1}{e_0(3-2e_1-e_0)+e_1}$ and the rate base review can help the regulator to bring the cap to a binding level with positive effects on productive efficiency.

4. Conclusions

This paper has presented an argument for believing that monopoly regulation can improve not only the market's allocative efficiency, but also the firm's productive efficiency by inducing the firm to supply more cost-reducing effort. We have analysed the effort-price choice by an unregulated monopolist, the socially optimal level of the same variables achieved by a perfectly informed regulator setting prices, their values in a context of imperfect information for the regulator and finally, the problems arising from the "ratchet effect".

Firstly we show that, whenever the regulated price is lower than the monopolist price, then also effort supplied by a regulated firm must be larger than the monopolist effort. Secondly, even a regulator equipped with a very poor information set, that is a regulator who knows only the past level of costs, can set a price-cap which induces the monopolist both to exert a higher level of effort than the one provided in absence of regulation and to be more cost-efficient throughout the whole regulatory period. This possibility arises under simple conditions, ultimately referable to the monopoly power of the firm and to the convexity of the effort disutility function. Note that such a result has been obtained under the most unfavourable conditions for the regulator, notably that the regulator has a very

poor information set and that it is infinitely risk-averse. Whenever we relax these assumptions, the regulator sets more binding caps and therefore the effect of price regulation on cost-efficiency is reinforced.

The results above are relevant at least under two points of view. From a theoretical point of view they add a further argument in favour of regulation of monopolies, in particular, in favour of price-cap regulation. A regulated monopoly may be more cost-efficient than an unregulated one.

From an operative point of view our results substantially contrast with the traditional analysis of the trade-offs arising in the choice of the optimal regulatory lag (Armstrong, Rees and Vickers, 1995). Indeed, not only the expected costs from allocative inefficiency, but also the expected costs from the productive inefficiency mentioned above may be increasing with the regulatory lag. A revision allows the regulator to set more binding prices thus inducing the monopolist to exert more cost-reducing effort in the future. Therefore, in setting the optimal regulatory lag, the regulator has to balance the expected costs which arise from allocative and productive inefficiency due to high prices with the well known adverse consequences on productive efficiency deriving from the ratchet effect. The rate base review, far from being a pure instrument to achieve allocative efficiency at the cost of moulding incentives to cost reduction, may itself perform a role in increasing productive efficiency.

Our paper highlights the crucial role of the elasticity of demand both in determining when regulation improves cost-efficiency and when a rate base review reinforces this beneficial effect. Notably, the idea that regulation increases productive efficiency when the elasticity of demand is sufficiently low adds another reason to the consolidated view that its benefits are directly correlated to the monopoly power of the firm. Within the range of the elasticity values for which price-cap regulation is desirable, reviews of the rate base increase productive efficiency when the elasticity is relatively higher. A pure fixed-price approach (i.e. a long regulatory lag) is to be preferred when the elasticity is lowest.

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