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A Model of Sliding-Scale Regulation[1]

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Abstract
Price caps, while widely touted, are less commonly implemented. Most incentive schemes involve profit sharing and are, thus, variants of sliding-scale regulation. I show that, relative to price caps, some degree of profit sharing always increases expected welfare. Numerical simulations show that welfare may be enhanced by large amounts of profit sharing and by granting the firm a greater share of gains than of losses. Simulations also suggest profit sharing is most beneficial when the firm's initial cost is high and cost-reducing innovations are difficult to achieve but offer the potential for substantial savings.

1. Introduction

For years economists have complained about the woefully poor incentives created by traditional rate-of-return regulation. Over the last decade, however, the institutional innovation of "price-cap regulation" has emerged, offering greatly enhanced incentives for efficient production and pricing.[2] Nevertheless, many if not most of the "incentive regulation" plans implemented in recent years do not simply cap prices. Typically they also include limits—-sometimes called "zones of reasonableness" or "deadbands"—-on how much the firm can gain or lose before triggering profit-sharing with customers.[3] Such regulatory

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2 Prominent examples in the United States include "price cap" regulation of AT&T by the Federal Communications Commission (FCC) and fixed reimbursement payments for given diagnostic-related groups under Medicare. A review of the extensive British experience with price caps is given by Armstrong, Cowan, and Vickers (1994).

3 The FCC's original price-cap plan for the interstate access charges levied by the local exchange carriers (LECs), enacted in 1991, offered LECs a choice between two different earnings-sharing plans. After the first three years of this plan, the FCC revised the schemes and added a third plan that involves no sharing. For more details, see Sappington and Weisman (forthcoming). Over half the states in the United States have adopted earnings sharing schemes, as discussed in detail by Greenstein, McMaster, and Spiller

schemes are known as ”sliding scale" (SS) plans. The recent enthusiasm for SS regulation has been something of a mystery to economists, since it does not appear to reflect a new theoretical case for its incentive effects. In fact, Braeutigam and Panzar (1993, 197) see SS regulation as “a classic case in which practice is far out ahead of theory” and note that (p. 195) “[i]n view of the widespread and continuing implementation of [sliding-scale] plans, especially at the state level, a modern analysis of their effects on firm behavior and economic efficiency is long overdue.” This paper attempts such an analysis.

The model presented here provides a strong efficiency rationale for SS regulation. The analysis revolves around the interplay between the firm’s incentives for cost-reducing innovation, the transaction costs of rate review, and the deadweight losses caused when prices and costs are not properly aligned. A comparative institutional approach is taken, using a modeling framework that encompasses rate-of-return regulation, price caps, and sliding scale regulation.[4] SS regulation is seen as a flexible combination of the other two alternatives, with profit-sharing used to balance the competing goals of providing incentives for cost reduction and of allowing price to track cost. The “deadband” reflects the high transaction costs associated with rate reviews and allows these costs to be avoided when the benefits of price adjustment are small. The results indicate that SS regulation, if properly designed, always offers greater welfare than pure price caps, which do not allow for price to adjust to cost ex post. The optimal sharing rule often involves substantial refunds of profits to consumers and may allow the firm to retain a greater share of gains than losses. The additional welfare benefits of profit-sharing over pure price caps are greatest when the firm has high costs and when cost-reducing innovations are difficult to achieve but offer the potential for substantial savings.

The remainder of the paper is organized as follows. Section 2 briefly surveys the literature. Section 3 presents the basic model. Section 4 analyzes the benchmark cases of cost-plus, rate-of-return, and price-cap regulation. Section 5 characterizes when sliding-scale regulation is welfare-enhancing relative to rate-of-return regulation and to price caps. Section 6 presents simulation results that extend the analytical results of section 5. Conclusions are offered in section 7.

2. Literature Review

The literature on profit-sharing is quite small.[5] Greenstein, McMaster, and Spiller (1995)

(1995). The prospective payment system (PPS) used by the Veterans’ Administration is designed so that a hospital cannot gain or lose more than 3% of its previous period’s budget. See Stefos, Lavallee, and Holden (1992, 5-6), for details. The California Public Utilities Commission (CPUC) has regulated transportation rates for some natural gas customers using what it calls a Negotiated Revenue Stability Account (NRSA) that “banded the effect that current incentive mechanisms could have on utilities’ returns to a 300 basis point difference from the authorized level.’’ See California Public Utilities Commission (1990, 19-20). Indiana has recently enacted a scheme for PSI Energy that gives the company all earnings below 10.6%, consumers all earnings beyond 12.3%, and uses a graduated sharing schedule between these two levels. See Indiana Utility Regulatory Commission (1990, 13).

4 Using a related framework, Cabral and Riordan (1989) and Clemenz (1991) study investment in cost reduction under rate-of-return regulation and under price caps. Neither paper considers cost- or profit-sharing, however, and their characterizations of rate-of-return and price-cap regulation differ significantly from those used here, as discussed in footnote 10 below.

5 There is, of course, an extensive literature on optimal regulation under conditions of adverse selection,

study empirically how state regulators' profit-sharing plans affect investment by local telephone exchange companies. They find that price-cap plans offer stronger incentives for investment than do profit-sharing plans. Similarly, Majumdar (1995) measures the technical efficiency of local exchange companies, finding that price caps induce greater efficiency gains than do profit-sharing plans. Since these studies ignore questions of allocative efficiency, however, they cannot offer a welfare assessment of the respective plans.

There is also a theoretical literature that addresses the welfare effects of profit-sharing schemes. Sappington and Sibley (1992) find that small amounts of profit-sharing may improve welfare relative to some forms of price-cap regulation when investment is observable; this result becomes ambiguous, however, when investment is unobservable. Weisman (1993), in a multiproduct setting, shows that various distortions which result when common costs are allocated across products can be avoided by the use of price caps, but not by the use of profit-sharing regulation. Gasmi, Ivaldi, and Laffont (1994) use numerical simulations to analyze profit-sharing for a monopolistic firm in an adverse selection setting with unobservable investment. They find that a deadband and profit-sharing are substitutes: either a deadband is used and all earnings outside it are rebated to consumers, or there is no deadband and profit sharing is employed. This dichotomy between regulatory plans bears little resemblance to the schemes used in practice, however, where deadbands and profit sharing appear to be complements rather than substitutes. Lyon (1995) shows that the combination of a deadband plus profit-sharing can induce the efficient choice between a conventional technology and an innovative technology whose costs are lower in expected value but higher in variance. Lyon and Huang (forthcoming) study incentives for the adoption of new technology when a firm under profit-sharing regulation competes with an unregulated firm. They find that, depending on the relative cost of innovation versus imitation, the industrywide rate of innovation may either speed up or slow down when the regulated firm is allowed to keep a larger share of profits.

This paper differs from the theoretical papers discussed above in several ways. Unlike Sappington and Sibley (1992), I focus on unobservable cost-reducing investment that has non- deterministic effects and on linear pricing schemes. I also use simulation analysis to investigate degrees of profit-sharing that depart significantly from price caps. Unlike Weisman (1993), I study a single-product firm in order to focus on the case where costs are uncertain and profits are returned to customers via price reductions rather than lump-sum transfers. Unlike Gasmi, Ivaldi, and Laffont (1994), the model presented here is fundamentally one of moral hazard, or hidden action, rather than hidden information.[6] Both types of model capture important aspects of reality, and the choice between them reflects beliefs about the relative importance of effort provision versus information revelation, as well as their

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much of which emphasizes the sharing of costs between the regulator and the firm. For a thorough treatment, see Laffont and Tirole (1993). Schmalensee (1989) analyzes a model in which price is a linear function of cost and provides a variety of interesting simulation results.

6 In the latter family of models, the principal typically distorts pricing behavior in subtle ways in order to minimize the informational rents earned by the agent possessing private information. Moral hazard models, on the other hand, usually trade off incentives for greater effort—generated by giving the agent a greater claim to residual surplus—against the cost such claimancy imposes on the risk-averse agent when outcomes are stochastic. My model differs from the typical moral hazard setup in that the firm is risk-neutral and allocative efficiency substitutes for risk-aversion as the brake on the use of high-powered incentives.

ability to explain and predict behavior. One appealing aspect of my simple model is that it provides a clear explanation for the complementary use of deadbands and profit sharing, which Gasmi et al. (1994) do not. This paper also differs from Gasmi et al. (1994) in that it returns excess earnings to consumers via price reductions (as is typically done in practice) rather than lump-sum transfers, and it does not impose ex post limited liability, so both the sharing of gains and of losses is allowed. The basic structure in the present paper is similar to that in Lyon (1995), but the earlier paper focuses on a positive analysis of the regulated firm's choice between discrete technological alternatives, while the current paper takes a broader view of social welfare that trades off productive and allocative efficiency. Finally, this paper differs from Lyon and Huang (forthcoming) in its focus on optimal profit-sharing rules for a regulated monopolist.

3. The Basic Model

In this section, I present a stylized model of firm behavior under regulation. The firm can invest in innovative efforts to reduce costs, the success of which cannot be predicted perfectly. Examples of such investments might include research and development, changes in the way the firm is organized, or the adoption of new production techniques. Regulators are assumed to be unable to observe the firm's effort directly.

The regulatory process as modeled here is motivated by an underlying process of interest group politics. As is well known, under Supreme Court decisions such as *Munn v. Illinois*, states can regulate profits in industries "affected with a public interest;" similarly, firms are entitled, under *Federal Power Commission v. Hope Natural Gas*, to seek rate increases when profits are low. As emphasized by Joskow (1974) and Peltzman (1976), however, interest groups wishing to affect the political process must incur the transaction costs of acquiring information and organizing for action; thus, interest group pressure for rate review tends to emerge only when economic conditions diverge significantly from those at the last review.

More formally, consider a risk-neutral single-product firm with constant marginal and average production cost c. Its initial cost is c_0, but this can be reduced, albeit with some uncertainty, depending on the amount e the firm expends on cost-reduction activities. There is thus a probability density function $f(c \mid e)$ with cumulative $F(c \mid e)$ that relates cost to effort. I assume $F(0,e) = 0$, $F(c_0 \mid e) = 1$, and that cost-reducing effort is subject to decreasing returns, i.e., $F_e(c \mid e) \geq 0 \geq F_{ee}(c \mid e)$. Both the regulator and the firm have access to historical data on prices and sales, but while the firm chooses e, the regulator cannot observe it. Let $\psi(e)$ represent the firm's disutility of effort, with $\psi'(e) > 0$ and $\psi''(e) > 0$.

I follow Banks (1992) in assuming that the firm's costs and earnings are observable but can only be verified for rate-making purposes by holding a formal rate review, which entails social costs of Δ.[7] At any point in time, the price from the most recent rate review, p_0, remains in effect unless a new rate review is held.

The basic price adjustment mechanism in this model is quite simple. An initial price p_0 is set less than or equal to the most recent observation of average (and marginal) cost, c_0. Given p_0, the firm's earnings *gross* of cost-reduction expenses are $R(c) \equiv [p_0 - c]q(p_0)$, and

7 The costs of the firm, consumer groups, and regulatory staff are all included in Δ.

net of cost-reduction expenses are $R(c) - \psi(e)$. The price remains unchanged as long as earnings remain within the "deadband," i.e., between a lower bound L and an upper bound U. These upper and lower bounds are shaped by the cost to interest groups (the firm and consumers, respectively,) of mobilizing to participate in the regulatory process. If $R(c) \notin [L,U]$, then any gross earnings outside the deadband are shared between ratepayers and shareholders, with α^L the firm's share of gross earnings below the deadband and α^U the firm's share of gross earnings above the deadband. Thus, allowed profits are

$$\pi(c \mid e) = \begin{cases} L + \alpha^L[R(c) - L] - \psi(e) & \text{if } R(c) < L \\ R(c) - \psi(e) & \text{if } R(c) \notin [L,U] \\ U + \alpha^U[R(c) - U] - \psi(e) & \text{if } R(c) > U. \end{cases} \tag{1}$$

I assume the regulator is unable to make use of lump-sum transfers and can only adjust profits by changing the output price p.[8] Thus, when $R(c) > U$, the regulator sets a new price p so that the new revenue requirement is $\mathscr{R}(c) = U + \alpha^U[R(c) - U] = \alpha^U R(c) + (1 - \alpha^U)U$. The price, p^U, that achieves this objective is found by setting $(p^U - c)q(p^U) = \alpha^U(p_0 - c)q(p_0) + (1 - \alpha^U)U$. A similar procedure applies for $R(c) < L$. It is not possible in general to obtain a closed-form solution to this pricing problem, although a solution can be found for specific demand functions.

The above structure captures as special cases several familiar regulatory schemes:

- Cost-plus (CP) regulation: $L = U = 0$, $\alpha^U = \alpha^L = 0$. Price, ex post, is always set equal to observed marginal cost.
- "Pure" price-cap (PC) regulation: $\alpha^U = \alpha^L = 1$. Price is set at an initial level $p_0 \le c_0$ and remains unchanged regardless of observed marginal cost.
- Rate-of-return regulation (RORR): $0 = L < U$, $\alpha^U = \alpha^L = 0$.[9] An initial price $p_0 = c_0$ is set and remains in place unless earnings are too high or too low. If earnings are too high, the firm reduces prices to avoid consumer outrage; if earnings are too low, the firm petitions for rate review and has price reset so as to just cover costs.[10]

In addition, the pricing rule described above allows for the more flexible structures being implemented in the industries mentioned above. Throughout the paper, I assume no "drastic" innovations are possible, i.e., even if cost is zero, the monopoly price $p^M(0)$ is at least p_0.[11]

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8 Schmalensee (1989) discusses this point at length.

9 See Braeutigam and Quirk (1984) for further discussion of this model of rate-of-return regulation.

10 There is some disagreement in the literature as to how rate-of-return regulation and price-cap regulation should be characterized. Schmalensee (1989) uses the static characterizations of cost-plus regulation and price-cap regulation given above; he does not explicitly model rate-of-return regulation. Cabral and Riordan (1989) and Clemenz (1991) model rate-of-return regulation as holding rate reviews at fixed intervals and price caps as allowing the firm to petition for a rate increase if and when it so chooses. Pint (1992), on the other hand, portrays RORR as giving the firm the right to initiate rate review, while under PC regulation reviews are held at fixed intervals. The empirical work of Joskow (1974) and Fitzpatrick (1987) supports the notion that traditional rate-of-return regulation gives the firm considerable power to manipulate the timing of rate reviews and, thus, comports with the modeling of Pint and of the present paper.

Define $c^U = p_0 - U/q(p_0)$ and $c^L = p_0 - L/q(p_0)$ as the cost levels at which the firm's earnings hit the upper and lower bounds on profits respectively. Then the relationship between price and cost for the three benchmark cases is as shown in figure 1.

The firm's expected profits can be written as

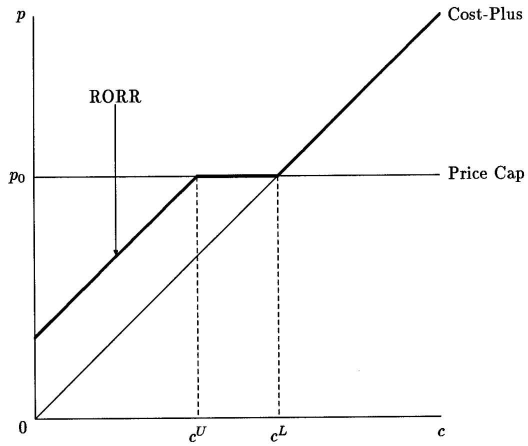

Figure 1. Pricing for Three Benchmark Cases

$$\bar{\pi}(e) = \int_0^{c^U} [(1-\alpha^U)U + \alpha^U(p_0 - c)q(p_0)]dF(c \mid e) + \int_{c^U}^{c^L} (p_0 - c)q(p_0)dF(c \mid e)$$
$$+ \int_{c^L}^{c_0} [(1-\alpha^L)L + \alpha^L(p_0 - c)q(p_0)]dF(c \mid e) - \psi(e). \quad (2)$$

Totally differentiating the firm's first-order condition with respect to effort, it is easy to show that $de/dL \leq 0$, $de/dU \geq 0$, $de/d\alpha^L \geq 0$, and $de/d\alpha^U \geq 0$. The intuition for the signs on these terms is straightforward: the firm increases its cost-reducing effort when it appropriates a greater share of the benefits of effort. This greater appropriation occurs if the upper (lower) bound on earnings is raised (lowered) or if the firm receives a larger share of any earnings beyond U or L.

Since price is a function of cost, expected consumer surplus is $\bar{S} = \int_0^{c_0} S(p(c))dF(c \mid e)$ or, more explicitly,

$$\bar{S} = \int_0^{c^U} S(p^U)dF(c \mid e) + S(p_0)[F(c^L,e) - F(c^U,e)] + \int_{c^L}^{c_0} S(p^L)dF(c \mid e). \quad (3)$$

11 As the term is used in the literature, a "drastic" innovation is one which so lowers the cost of production that the monopoly price, based on the new cost, is below the original cost. If a firm in a competitive industry developed a drastic innovation, it would thus drive all its rivals out of business.

Total surplus (which I will refer to as "welfare") is $\overline{W} = \overline{S} + \overline{\pi}$ and will be the focus of much of the analysis to follow. Many normative models of regulation give profits a strictly smaller weight in regulatory objectives than consumer surplus. In a moral hazard model such as the one presented here, however, the weight placed on profits is relatively unimportant, since welfare maximization drives the firm to its reservation level, here assumed to be zero expected profits. Thus, only Proposition 4 of the paper would be affected if profits were weighted less than consumer surplus; these changes are discussed explicitly after the proposition is presented.

Differentiating expected consumer surplus with respect to α^U yields

$$\frac{d\overline{S}}{d\alpha^U} = \frac{\partial \overline{S}}{\partial \alpha^U} + \frac{\partial \overline{S}}{\partial e}\frac{de}{d\alpha^U}. \tag{4}$$

The first term (the "allocative effect") is always negative, since it requires price increases to consumers. The second additive term (the "incentive effect") is positive. As mentioned above, $de/d\alpha^U \geq 0$. Integrating (3) by parts and partially differentiating with respect to e yields

$$\frac{\partial \overline{S}}{\partial e} = \int_0^{c^U} q(p^U)\,\frac{dp^U}{dc}\,F_e(c \mid e)dc + \int_{c^L}^{c_0} q(p^L)\,\frac{dp^L}{dc}\,F_e(c \mid e)dc.$$

It can be shown that $dp^U/dc > 0$ and that if $L \leq 0$ then $dp^L/dc > 0$. Thus, if $L \leq 0$, then $\partial\overline{S}/\partial e > 0$, and the incentive effect of α^U on consumer surplus is positive. Similar expressions can be derived for α^L.

4. Benchmark Cases

I next examine the performance of the three benchmark regulatory systems outlined above.

4.1. Cost-Plus Regulation

Pure cost-plus (CP) regulation has $\alpha^L = \alpha^U = 0$ and $L = U = 0$, so that $p = c$ ex post. Because the firm's cost-reducing effort is unobservable, these costs are never recovered in rates and $\overline{\pi}(e) = -\psi(e)$. The firm has no incentive to reduce its costs and $e^* = 0$. As a result, price does not fall, expected profits are zero, and consumer surplus is governed entirely by the initial regulated price, e.g., $\overline{S}(e^*) = S(p_0)$. This form of regulation has received much public condemnation, but it is essentially a caricature. Authors such as Joskow and Schmalensee (1986) have discussed at length why traditional rate-of-regulation differs from a simple cost-plus format.

4.2. Rate-of-Return Regulation

Traditional rate-of-return regulation (RORR) is characterized by $p_0 = c_0$, $0 = L < U$, and $\alpha^L = \alpha^U = 0$. Then (2) becomes

$$\overline{\pi}(e) = \int_0^{c^U} U dF(c \mid e)dc + \int_{c^U}^{c_0} (p_0 - c) q(p_0) dF(c \mid e) - \psi(e). \tag{6}$$

Integrating by parts and differentiating with respect to effort, the firm's first-order condition becomes

$$\frac{d\overline{\pi}}{de} = q(p_0) \int_{c^U}^{c_0} F_e(c \mid e)dc - \psi'(e) = 0. \tag{7}$$

The presence of the "deadband" means that RORR induces a positive level of effort and, thereby, generates lower expected costs than cost-plus regulation. Furthermore, both the firm and consumers are better off than under CP regulation. The deadband allows the firm to keep some of the benefits of cost reduction, while consumers benefit because prices will be reduced for sufficiently large cost reductions.[12] These benefits are even greater when the transaction costs of rate review are recognized: the deadband economizes on the transaction costs of rate review when costs have changed little since the last rate review.

4.3. Price Caps

Pure price-cap (PC) regulation has $\alpha^L = \alpha^U = 1$, so $p = p_0$ ex post regardless of cost. (Because I assume $p^M(0) > p_0$, downward price flexibility makes no difference.) Thus, equation (2) reduces to $\overline{\pi}(e) = \int_0^{c_0} (p_0 - c) q(p_0) dF(c \mid e) - \psi(e)$, and, after integrating by parts, the firm's first-order condition is

$$\frac{d\overline{\pi}}{de} = q(p_0) \int_0^{c_0} F_e(c \mid e)dc - \psi'(e) = 0. \tag{8}$$

Obviously, $\overline{S}(e^*) = S(p_0)$. Thus, under pure price caps, consumers do exactly as well as they do under cost-plus regulation *if* the same initial price p_0 is used in both regimes. The firm, however, makes greater profits under price caps. The regulator can thus set the initial price cap lower than c_0 and capture for consumers some of the benefits of cost reduction. This is demonstrated in Lemmas 1 and 2 below.

Lemma 1. Under pure price cap regulation, (a) there exists a price $\underline{p}$ below which expected profit is negative. (b) For $p_0 > \underline{p}$, $de/dp < 0$.

Proof: See Appendix. Q.E.D.

Lemma 1 shows that lowering the initial price induces greater effort as long as the price is above $\underline{p}$.[13] Lemma 2 characterizes the social-welfare maximizing price under pure

12 Note that the deadband plays a role similar, but not identical, to that of regulatory lag in dynamic models of regulation. The time period between rate reviews is driven by two components. First, because of the transaction costs of triggering a rate review, such a review will not be triggered until economic conditions depart significantly from those at the last review. Second, once review is triggered, there is a "processing lag" that reflects the time delays inherent in legal adjudication. The present paper reflects only the first of these aspects of regulatory lag.

price-cap regulation.

Lemma 2. Under pure price-cap regulation, if expected profits are kept non-negative, welfare is maximized at $p_0 = \underline{p}$.

Proof: Let $\overline{W}^*(p_0)$ and $\overline{\pi}^*(p_0)$ be expected welfare and expected profits respectively at the firm's optimal level of effort. It is straightforward to show that

$$\frac{d\overline{W}^*(p_0)}{dp_0} = q'(p_0)\frac{\overline{\pi}^*(p_0)}{q(p_0)}. \tag{9}$$

For any price cap that leaves $\overline{\pi}^*(p_0) \geq 0$, welfare is decreasing in price. Welfare is thus maximized at $p_0 = \underline{p}$. Q.E.D.

It follows immediately that since $\underline{p} < c_0$, price caps can be designed so as to Pareto-dominate cost-plus regulation.[14] The effort level and expected cost induced by PC are compared to those under RORR and CP regulation in Proposition 1.

Proposition 1. The firm's effort under price-cap regulation is greater than that under rate-of-return regulation, which is greater than that under pure cost-plus regulation. The firm's expected cost under price-cap regulation is less than that under rate-of-return regulation, which is less than that under pure cost-plus regulation.

Proof: See the Appendix. Q.E.D.

Proposition 1 is quite consistent with intuition. Price caps are designed to maximize effort by inducing the firm to act as a price taker. Cost-plus regulation induces no effort, since the firm cannot recover its cost of effort. Finally, RORR involves rigid prices in the short run, is cost-plus in the long run, and thus is intermediate between cost-plus and price cap regulation.[15] Not surprisingly, then, the firm's choice of effort under RORR is between that under cost-plus and price caps.[16]

While it is possible to rank the above schemes in terms of the effort they induce, welfare comparisons are ambiguous. Under RORR, (3) can be integrated by parts to yield

$$\overline{S} = S(p_0) + \int_0^{c^U} q(p^U)\,\frac{dp^U}{dc}\,F(c \mid e)dc. \tag{10}$$

Because $dp^U/dc > 0$, RORR generates greater consumer surplus than does pure PC regulation, assuming the same initial price $p_0 = c_0$. RORR offers consumers two benefits: first, it adjusts price closer to marginal cost when profits rise "too" high, and second, because

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13 The results of Lemma 1 are similar to those of Cabral and Riordan (1989) in their Propositions 3.1 and 3.2, but Lemma 1 applies for all p_0, not just $p_0 = c_0$.

14 Because welfare-maximization requires expected profits be set to zero, the weight on profits in the welfare function has no impact on Lemma 2.

15 Joskow and Schmalensee (1986) discuss this point extensively.

16 Despite our different modeling of RORR and PC regulation, this result parallels Proposition 4.1 of Cabral and Riordan (1989).

$p_0 = c_0$, there is no possibility of costs above c_0, so a sharing rule never forces consumers to bear responsibility for negative profit outcomes.[17] However, if the price-cap scheme begins with an initial price $p_0 < c_0$—and this is clearly the intent of price-cap regulation—the comparison is in general ambiguous.[18]

5. Sliding-Scale Regulation

This section examines the performance of sliding-scale regulation relative to RORR and to price caps. It is assumed throughout that $L \leq 0$ and $U \geq 0$. A complete characterization is not possible using analytical techniques, but marginal shifts away from RORR or PC and toward SS are examined in Propositions 2 and 3. Proposition 4 shows that profit-sharing, implemented via lump-sum transfers, never produces greater total surplus than price caps. In addition, Proposition 5 provides sufficient conditions for a deadband to be a welfare-improving part of SS regulation.

Proposition 2 addresses the question of whether profit-sharing improves upon rate-of-return regulation.

Proposition 2. Relative to rate-of-return regulation, a small increase in α^U increases welfare for small enough U; for large U the welfare effects of profit-sharing are ambiguous in general.

Proof: See the Appendix. Q.E.D.

Proposition 2 shows that profit-sharing is welfare- increasing for small enough U. This is easy to understand because as U becomes small, RORR approaches cost-plus regulation, which provides no incentive for effort. In this situation, the allocative distortions caused by setting $\alpha^U > 0$ are swamped by the beneficial incentive effects.[19] The next proposition addresses the shift from PC to SS.

Proposition 3. Relative to pure price-cap regulation, welfare can always be increased through a small decrease in α^L and a small decrease in α^U, which jointly leave expected profits unchanged.

Proof: See the Appendix. Q.E.D.

Proposition 3 establishes conditions under which profit-sharing enhances welfare relative

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17 In practice, price-cap regulation allows for price reduction if the firm's costs are so low that the monopoly price is below p_0. (This of course will never happen if drastic innovations are impossible.) As long as the upper bound U on profits is below the monopoly profit level, consumers will experience price reductions in more states of the world under RORR than under price caps.

18 This ambiguity, which parallels the results of Schmalensee (1989), reflects the idea that a price cap sacrifices price flexibility to achieve stronger incentives. My model thus differs sharply from that of Clemenz (1991), who concludes that PCs can always be designed so as to produce higher welfare than RORR. The main reason is that Clemenz's "price caps" have upward price flexibility. See footnote 10 for further discussion of our respective assumptions.

19 For U close to zero, this result holds regardless of the weighting of profits in the welfare function. An increase in α^U always increases profits. Furthermore, as U goes to zero, any increase in incentives must benefit consumers as well, since otherwise they have no hope of a price reduction.

to pure price caps.[20] The basic notion is simple: when $\alpha^U = \alpha^L = 1$, sharing produces a first-order allocative gain, but only a second-order loss in the form of weakened incentives.[21]

It is also worth pointing out that welfare is not increased by adding profit-sharing to a price-cap scheme if profits are returned to customers as a lump sum. This is shown in Proposition 4.

Proposition 4. Relative to pure price cap regulation, profit-sharing with benefits distributed to consumers through lump-sum transfers reduces welfare.

Proof: Consider pure PC regulation with some initial price p_0. While lump-sum transfers ex post have no impact on total welfare, any transfer of profits away from the firm reduces its cost-reducing effort, raising expected costs and reducing expected welfare. Welfare losses are exacerbated if price must be increased to keep expected profits non-negative. Q.E.D.

Proposition 4 provides a rationale for why profit-sharing schemes commonly refund shared earnings to customers via price reductions rather than lump-sum transfers. Note, however, that it need not hold if profits receive little weight in the welfare function, since if profit is unimportant, pure transfers from the firm to consumers raise welfare. Similarly, transfers to particular favored groups of customers might be desired by regulators. Such regulatory preferences may explain the provisions in some state regulations that require shared earnings to be invested in network modernization for specific customer groups.[22]

Finally, I return to the question of the welfare effects of a deadband. In section 4, it was easy to see that the deadband embedded in RORR improves upon pure cost-plus regulation, since it both enhances the firm's incentive to exert effort and economizes on regulatory costs in situations where costs have changed little since the last rate review. Proposition 5 examines the welfare effects of a deadband in the more general case where profit-sharing is allowed. Let Δ be the transaction costs of a rate review; this would include, for example, the organizational costs of consumers, the fees of lawyers and consultants, and the opportunity cost of allocating some of the firm's employees to rate case preparation. Total welfare is now

$$\overline{W} = \overline{S} + \overline{\pi} - \Delta[1 - F(c^L \mid e) + F(c^U \mid e)]. \tag{11}$$

Proposition 5. A deadband, i.e., a pair of parameters L and U with $L \leq 0 \leq U$, where at least one of the inequalities is strict, enhances welfare if the demand curve is downward-sloping and the transaction costs of rate review are large enough.

Proof: See the Appendix. Q.E.D.

Proposition 5 shows that the allocative distortions created by a deadband must be balanced against the enhanced incentives and the reduced transaction costs the deadband provides.

20 Because the proposition requires expected profit to remain unchanged, it is clearly not affected by the weight of profits in the welfare function.

21 Proposition 3 is similar to Findings 6 and 7 in Sappington and Sibley (1992), though those authors do not allow for a deadband and they require $\alpha^L = \alpha^U$. In both models, however, the key is that profit-sharing improves allocative efficiency.

22 See Greenstein et al. for details on the various plans.

As long as the demand curve is downward-sloping, allocative distortions are bounded, so a deadband enhances welfare if Δ is large enough. Even if $\Delta = 0$, a deadband might enhance welfare if the resulting allocative distortions are smaller than the incentive effects; this might happen, for example, if c_0 is small enough that the allocative effects of loss-sharing are minor.[23]

To summarize the key results of this section, profit-sharing cannot necessarily improve upon rate-of-return regulation, but it can always offer an improvement over pure price caps, assuming profit-sharing is implemented via price changes. Furthermore, a deadband is a welfare-enhancing component of SS regulation if the transaction costs of rate review are large enough. These results are limited, however, since they only address marginal changes in the amount of profit-sharing. To obtain further insight into the effects of large changes in the extent of profit-sharing, the following section presents the results of a numerical simulation analysis.

6. Simulation

This section reports results of a numerical simulation of the foregoing model of sliding-scale regulation. Its purpose is two-fold: 1) To examine whether sharing rules that are significantly different from $\alpha^L = \alpha^U = 1$ can improve welfare relative to pure price caps, and 2) To study the relationship between changes in exogenous parameters and changes in the welfare-maximizing values of the choice variables.

The simulation uses a linear demand function $q = 10 - p$, with $\psi(e) = e^2$, and considers a range of initial cost levels from $c_0 = 1$ to $c_0 = 9$.[24] The probability distribution on costs is

$$F(c \mid e) = 1 - \left(1 - \frac{c}{c_0}\right)^{de},$$

with corresponding density function

$$f(c \mid e) = \frac{de}{c_0}\left(1 - \frac{c}{c_0}\right)^{de - 1}$$

and likelihood ratio

$$\frac{f_e(c \mid e)}{f(c \mid e)} = \frac{1}{de} + \ln\left(1 - \frac{c}{c_0}\right).$$

This density function generates an expected value of cost

$$\bar{c}(e) = \frac{c_0}{de + 1}.$$

Thus, d is a measure of the efficiency of the cost-reduction technology. The cumulative

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23 Note that the proposition continues to hold if profit receives a low weight in the welfare function, since the deadband retains its important role in reducing transaction costs.

24 The costs of rate review are not included in the simulation, so a deadband is not examined.

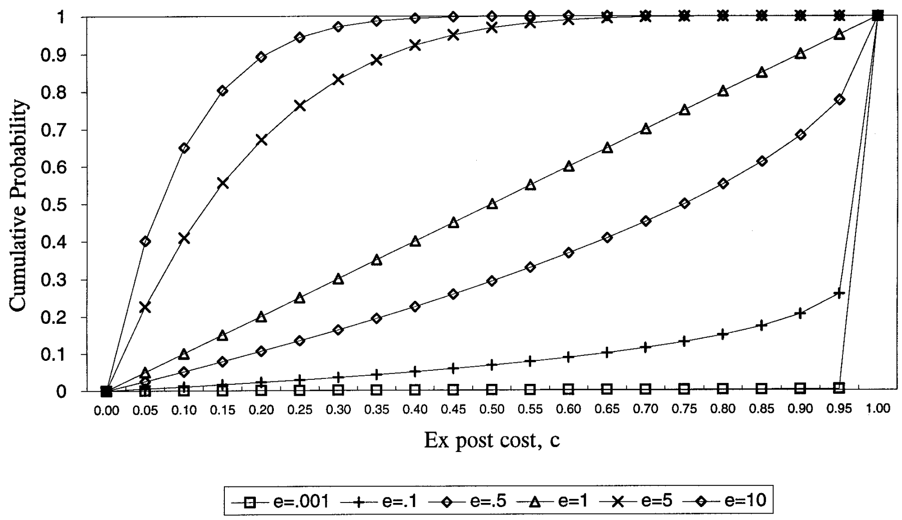

Figure 2. Probability Distribution on Costs for Alternative Effort Levels

distribution is shown in figure 2 for several alternative effort levels.[25] It has the appealing properties that, if the firm exerts no effort then cost is c_0 with certainty, and that expected costs decline monotonically with effort.

Price Cap Regulation

The optimal pure price cap $\underline{p}$ is shown in figure 3 for various levels of initial average cost

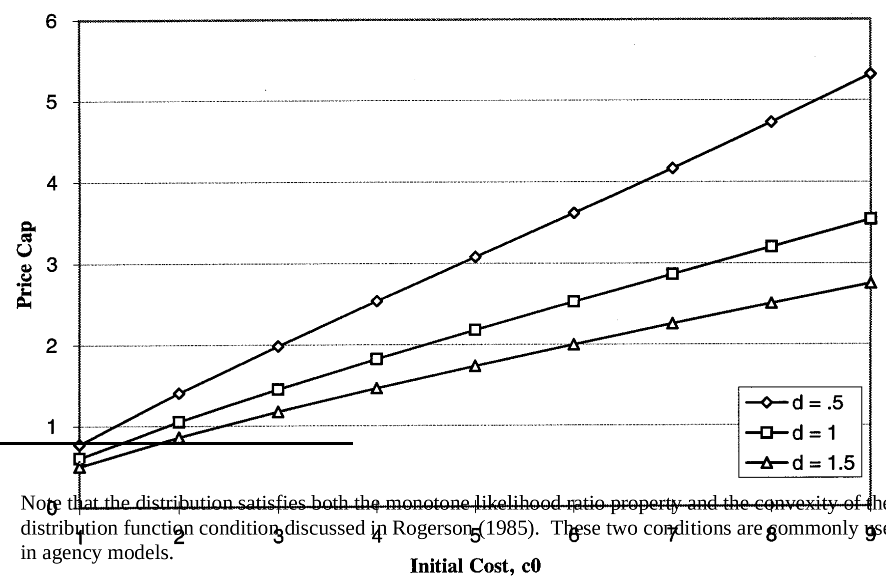

Figure 3. Optimal Price Caps for Various Cost-Reduction Efficiencies

25 Note that the distribution satisfies both the monotone likelihood ratio property and the convexity of the distribution function condition discussed in Rogerson (1985). These two conditions are commonly used in agency models.

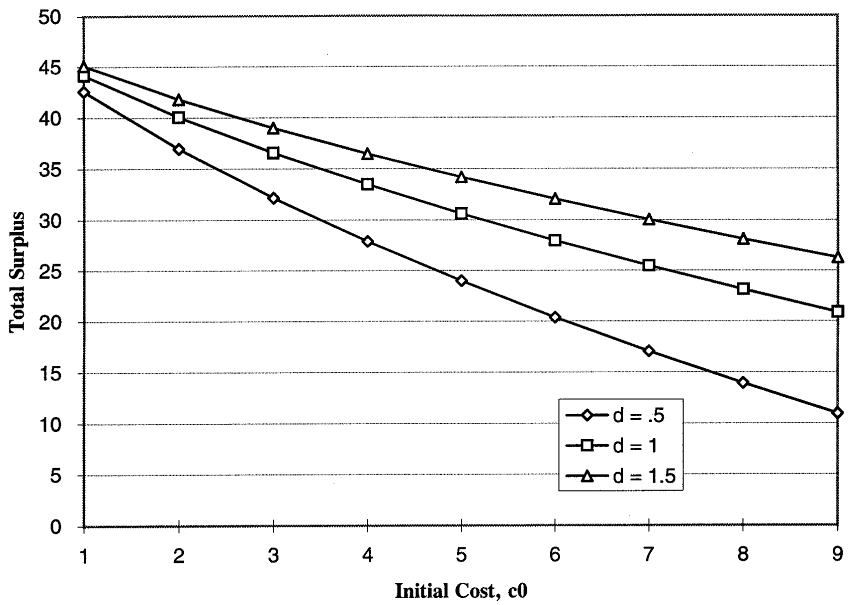

Figure 4. Welfare under Optimal Price Caps

c_0 and efficiency of cost reduction d. While the cap increases with c_0, $d\underline{p}/dc_0$ is well below 1 for all cases examined. In addition, the slope $d\underline{p}/dc_0$ diminishes as the cost-reduction technology becomes more efficient, i.e., as d increases. The corresponding levels of total welfare are shown in figure 4. As one would expect, welfare increases with the efficiency of the cost-reduction technology. An efficient technology also helps offset the welfare-reducing effect of a high initial cost.

Sliding-Scale Regulation

A major purpose of the simulation is to study the characteristics of welfare-maximizing profit-sharing rules. The approach taken here was to first solve for the optimal pure price cap and then, holding the price cap fixed, solve for the welfare-maximizing sharing levels.[26] It should be noted from the outset that monotonic relationships between the level of profit sharing and exogenous parameters such as c_0 and d cannot be expected. Milgrom and Shannon (1994) provide necessary and sufficient conditions for such monotone comparative statics to emerge, and these conditions are not met in my model of sliding-scale regulation.[27]

26 This procedure was adopted primarily to reduce the computational burden of the simulations. Preliminary tests indicated the optimal price level was very insensitive to the presence of profit sharing. Gasmi et al. (1994) also found that the introduction of profit sharing typically has little impact on the optimal price level.

27 The two conditions are: 1) the objective function is supermodular in the choice variables, and 2) the objective function has increasing differences in the choice variables and the exogenous parameters. For smooth functions in $\mathscr{R}^N$, these conditions simplify to restrictions on the cross-partial derivatives of the objective function. In my model, both conditions fail because $\partial^2 W/\partial\alpha^U\partial p_0$ and $\partial^2 W/\partial\alpha^U\partial c_0$ are ambiguous in sign.

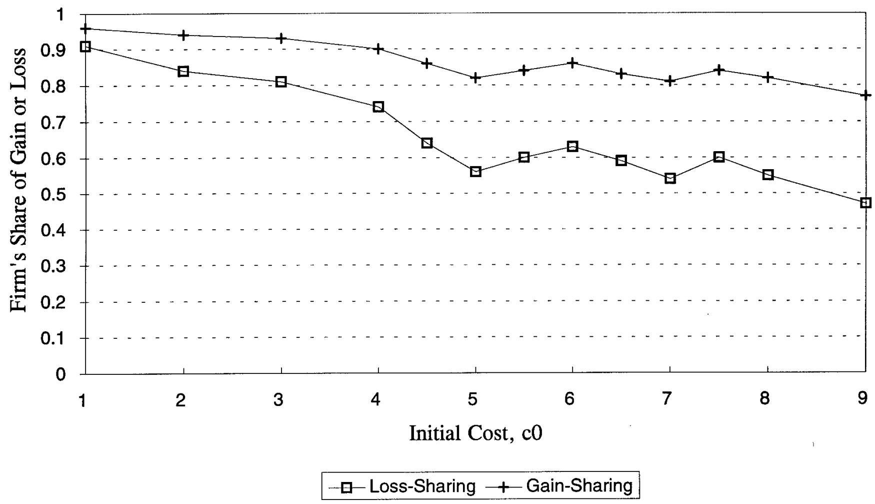

Figure 5. Welfare-Maximizing Sharing Rules ($d = 1$, $L = U = 0$)

The firm's share of gains and losses under welfare-maximizing SS regulation is shown in figures 5 and 6 for various levels of c_0 and d. Several observations are worthy of note. First, in all cases examined, the firm's share of gains, α^U, is greater than its share of losses, α^L; hence, the profit function is convex in observed cost. This convexity may help induce the firm to undertake the risks of investing in cost reduction. Second, loosely speaking, the

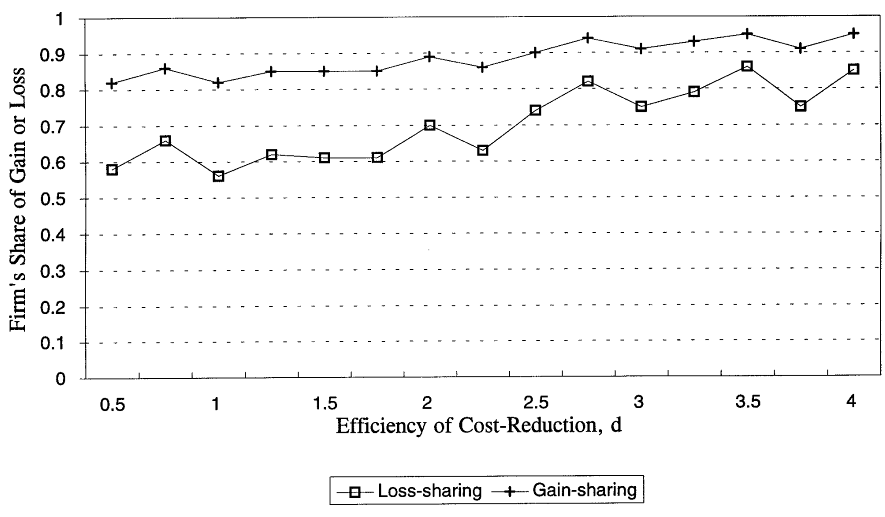

Figure 6. Welfare-Maximizing Sharing Rules ($c0 = 5$, $L = U = 0$)

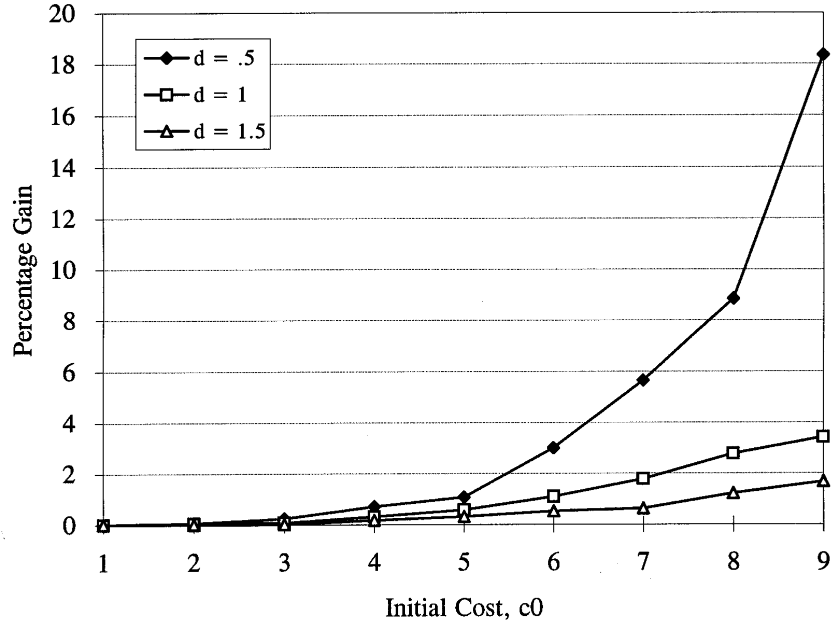

Figure 7. Welfare Gain: Price Caps to Sliding Scale

welfare-maximizing values of α^L and α^U decline with increases in c_0, though the decline is certainly not monotonic. With higher initial cost, there is a wider range of possible ex post cost levels, and hence price flexibility is more important. Third, loosely speaking, the welfare-maximizing values of α^L and α^U rise with increases in *d*, though again the decline is not monotonic. A more efficient cost-reduction technology reduces the chance that a high cost realization will occur and makes price flexibility less important.[28]

The percentage welfare gain in adding optimal profit sharing to the optimal price cap is shown in figure 7. For low levels of c_0, profit-sharing offers very little gain over pure price caps. The narrow range of possible future costs makes price flexibility unimportant. The benefits of profit-sharing increase with c_0 and decrease with the efficiency of the firm's cost-reduction technology; when $c_0 = 9$ and $d = .5$, SS regulation provides an improvement of more than 18% relative to pure price caps.

The above results contrast sharply with the simulation findings from the adverse selection model of Gasmi, Ivaldi, and Laffont (1994). They find that the sliding-scale rule that maximizes the sum of consumers' surplus and profits is essentially rate-of-return regulation, i.e., a scheme that has $U > 0$ but $\alpha^U = 0$; in addition, they find that price is always greater than cost ex post. These differences stem from two underlying differences in our respective

28 The second and third observations parallel the standard result in adverse selection models that the most efficient type of firm receives the strongest incentives.

models. First, Gasmi et al. redistribute shared profits to consumers via a lump-sum transfer rather than a change in price, so profit-sharing has no allocative efficiency effects. Second, they impose ex post limited liability for even the least efficient firm, so loss-sharing is never a possibility.

It is interesting to compare the qualitative nature of the simulated sharing rules with the sharing plans put into practice. Greenstein et al. (1995) summarize several recent surveys of state incentive regulation plans for telecommunications, many of which include profit sharing. The general pattern they report shows firms' share of profits tends to fall as the level of profits rises; many schemes return all profits above a certain level to ratepayers. This pattern runs counter to the welfare-maximizing policy identified by the simulation. Presumably the political pressures on regulators make it difficult to allow firms to keep a large share of profits when profits are high.

A final case study is provided by the profit-sharing plan used by Medicare for psychiatric hospitals. Under the so-called TEFRA[29] system implemented in 1982, if hospitals reduced their costs below a target level, they could keep 50% of gains up to a maximum of 5% of the target. If costs were above the target, however, the hospital had to cover 100% of the excess. Thus, $\alpha^U = .5 < \alpha^L = 1.0$, a plan that runs counter to the above findings for optimal sliding-scale regulation. Interestingly, TEFRA was modified for 1992 implementation to incorporate loss-sharing provisions symmetric with those for gain-sharing. While the simulation results above suggest that loss-sharing probably should have been even more extensive than gain-sharing, the change represents a big step in the direction of efficiency.[30]

7. Conclusions

This paper has presented a formal model of sliding-scale regulation and its benefits relative to rate-of-return regulation and price-cap regulation. While profit-sharing does not necessarily offer an improvement over rate-of-return regulation, some degree of profit- and loss-sharing outside a deadband improves social welfare relative to pure price-cap regulation. Simulation results show that a significant departure from pure price caps—that is, sharing a substantial portion of profits with ratepayers—may be welfare-enhancing. Furthermore, it may be desirable from a welfare perspective to allow the firm to retain a greater share of gains than of losses, though political pressures may militate against such a policy. Simulation also suggests that the additional welfare benefits of profit-sharing over pure price caps are greatest when the firm's initial cost is high and cost-reducing innovations are difficult to achieve.

While the results of this paper are fairly simple and intuitive, they were obtained under some restrictive assumptions. I assumed a single-product firm in a static setting, with no exogenous shocks to costs or demand. In addition, the regulator was assumed to know the firm's underlying production technology, i.e., there was no adverse selection problem. Finally, I made no attempt to distinguish between capital costs and operating costs; since most sliding-scale schemes use the firm's rate-of-return on capital, this distinction may be

29 This system was created as part of the Tax Equity and Fiscal Responsibility Act of 1982, hence the acronym.

30 For a discussion and critique of the initial TEFRA rules, see Cromwell, Ellis, Harrow and McGuire (1991).

important. A full understanding of sliding-scale regulation will only be achieved by integrating these considerations into the analysis.

Appendix

Proof of Lemma 1: (a) As noted above, under pure price caps, expected profits are $\bar{\pi}(e,p_0) = \int_0^{c_0} (p_0 - c)q(p_0)dF(c \mid e) - \psi(e)$. Then, by the envelope theorem,

$$\frac{d\bar{\pi}(e^*,p_0)}{dp_0} = \int_0^{c_0} [q(p_0) + (p_0 - c)q'(p_0)]dF(c \mid e).$$

By assumption, no drastic cost reduction is possible, and $p^M(0) > p_0$. Thus, revenue is increasing in p_0, so $q(p_0) + p_0q'(p_0) > 0$. Since $- cq'(p_0) > 0$, expected profits are increasing in p_0. It is clear that if $p_0 > c_0$ then $\bar{\pi} > 0$ and if $p_0 = 0$ then $\bar{\pi} < 0$. Since $\bar{\pi}$ is continuous in p_0, there exists some $\underline{p} > 0$ such that $\bar{\pi}(e^*,\underline{p}) = 0$ and $\bar{\pi}(e^*,p) < 0$ for all $p < \underline{p}$.

(b) Totally differentiating (8) and rearranging terms yields

$$\frac{de}{dp_0} = \frac{- q'(p_0) \int_0^{c_0} F_e(c \mid e)dc}{q(p_0)\left[\int_0^{c_0} F_{ee}(c \mid e)dc - \psi''(e)\right]} < 0. \tag{12}$$

Q.E.D.

Proof of Proposition 1: Suppose the same initial price p_0 holds under all regimes. Let e^{RORR} solve (7), and e^{PC} solve (8). Note that (7) and (8) are identical except that the integral in (8) has a smaller lower limit of integration. Thus, the price-cap firm's expected profits at e^{RORR} are increasing in e. Because $F_{ee}(c \mid e) < 0$, $e^{PC} > e^{RORR}$. This is true a fortiori if the initial price under price caps is less than that under RORR. It is apparent from (7) that $e^{RORR} > 0$, but under cost-plus regulation effort is $e^{CP} = 0$. Thus $e^{RORR} > e^{CP}$. Expected costs are always decreasing in effort because $F_e(c \mid e) \geq 0$. Q.E.D.

Proof of Proposition 2: Under RORR,

$$\left.\frac{d\bar{W}}{d\alpha^U}\right|_{\alpha^U = 0} = \int_0^{c^U} \left[(p^U - c)q'(p^U)\frac{[(p_0 - c)q(p_0) - U]}{q(p^U) + (p^U - c)q'(p^U)}\right]dF(c \mid e)dc$$

$$+ \left.\frac{\partial\bar{W}}{\partial e}\frac{\partial e}{\partial\alpha^U}\right|_{\alpha^U = 0}. \tag{13}$$

Note that the integral term (the allocative effect $\partial\overline{W}/\partial\alpha^U$) is negative, while the second additive term (the incentive effect) is positive. Thus, in general the sign of (13) is ambiguous. However, if $U = 0$, then $p^U = c$, and the integral term is exactly zero; welfare increases with α^U. Since (13) is continuous in U, profit-sharing is welfare-increasing for small positive values of U as well. Q.E.D.

Proof of Proposition 3: Under pure price-cap regulation, $\partial p^L/\partial c = \partial p^U/\partial c = 0$, and $\partial\overline{S}/\partial e = 0$. Straightforward calculations yield

$$\left.\frac{d\overline{W}}{d\alpha^L}\right|_{\alpha^L=1} = \int_{c^L}^{c_0}\Big[(p_0 - c)q(p_0) - L\Big]\left[1 - \frac{q(p_0)}{q(p_0) + (p_0 - c)q'(p_0)}\right]dF(c \mid e)dc < 0. \tag{14}$$

By the definition of c^L, $(p_0 - c)q(p_0) - L < 0$ for $c > c^L$; thus, the first term in brackets within the integral is negative. Further, if $L \le 0$, then $c > c^L$ implies $p_0 < c$; thus, the second bracketed term within the integral is positive. The integral as a whole is negative, so a small decrease in α^L increases welfare.

Similarly,

$$\left.\frac{d\overline{W}}{d\alpha^U}\right|_{\alpha^U=1} = \int_0^{c^U}\left[\frac{\partial\pi}{\partial p^U} + \frac{\partial S}{\partial p^U}\right]\frac{\partial p^U}{\partial\alpha^U}dF(c \mid e)$$

$$= \int_0^{c^U}\left[(p^U - c)q'(p^U)\,\frac{[(p_0 - c)q(p_0) - U]}{q(p^U) + (p^U - c)q'(p^U)}\right]dF(c \mid e)dc < 0. \tag{15}$$

Since c^U defines the cost level below which earnings exceed U, $p^U - c > 0$ for all $c < c^U$. Thus, the first multiplicative term within the integral is positive. Demand is downward-sloping, so the second term is negative. Since $p_0 < p^M(0)$ by assumption, the denominator of the last term—which is equal to the marginal change in revenue with an increase in price—is positive. Finally, $(p_0 - c)q(p_0) - U > 0$, and the numerator of the last term is negative. Thus, the integral as a whole is negative, and a small decrease in α^U increases welfare. Since $\alpha^L < 1$, profits remain non-negative. Q.E.D.

Proof of Proposition 5: Differentiating welfare with respect to U yields

$$\left.\frac{d\overline{W}}{dU}\right|_{U=0} = \frac{\partial\overline{W}}{\partial U} + \frac{\partial\overline{W}}{\partial e}\frac{\partial e}{\partial U} + \Delta\left[f(c^U \mid e)\,\frac{\partial c^U}{\partial U} + F_e(c^U \mid e)\,\frac{\partial e}{\partial U}\right]. \tag{16}$$

The first additive term is negative, representing the loss of allocative efficiency created when a deadband makes price unresponsive to cost. The second additive term is positive due to the enhanced incentive for cost reduction provided by the deadband. The third additive term is positive because a larger deadband generates fewer costly rate reviews. Thus, if the first term is bounded, there exists some Δ

large enough to make a deadband desirable. Suppressing the dependence of p^U on c, straightforward calculation shows that

$$\left.\frac{\partial \overline{W}}{\partial U}\right|_{U=0} = (1-\alpha^U)\int_0^{p_0} \frac{(p^U - c)q'(p^U)}{q(p^U) + (p^U - c)q'(p^U)} dF(c \mid e)dc$$

$$< \max_c \frac{(p^U - c)q'(p^U)}{q(p^U) + (p^U - c)q'(p^U)}. \tag{17}$$

The denominator of this last expression is positive, since p^U is less than the monopoly price. Since $q'(p)$ is finite, the numerator is bounded. Hence the size of the allocative effect is bounded, and there exists some Δ large enough that $d\overline{W}/dU > 0$ at $U = 0$. A similar argument can be made for $L < 0$. Q.E.D.

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