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ABSTRACT

Price Regulation, Investment and the Commitment Problem*

We consider a dynamic model of price regulation with asymmetric information where strategic delegation is available to the regulator. Firms can sink non-contractible, cost-reducing investment but regulators cannot commit to future price levels. We fully characterize the Perfect Bayesian equilibria and show that, with incentive contracts but without delegation, under- and over-investment can occur. We then show that delegation to a suitable regulator can both improve investment incentives and ameliorate the ratchet effect by credibly offering the firm future rent. Simulations indicate significant welfare gains from these two effects and that a wide range of regulatory preferences can achieve this result.

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NON-TECHNICAL SUMMARY

Investment in cost-reducing technology is an important strategy for ensuring efficient production, not least in capital-intensive utilities. To the extent that investment costs are incurred before lower costs are achieved, regulated utilities face a well-known risk as to their ability to recoup investment costs. In particular, the regulator may be unable to commit to maintaining future prices at a level sufficient to reimburse sunk investment costs. Instead, the regulator's allocative objectives (where efficiency requires prices to reflect marginal costs of production) may conflict with those of dynamic efficiency: the inability to commit may lead to under-investment by the utility.

There are numerous examples of investment decisions being postponed because of uncertainty about the future bearing of regulatory policy. For example, Newbery (1999) cites a variety of British and overseas experiences to illustrate the point.[1] These range from delays to tramway electrification in nineteenth-century Britain as a result of impending munipalization, to suspended investment in the Bolivian electricity sector because of license-renewal negotiations. The regulation of privatized utilities in Britain has provided numerous recent cases, with debates between Train Operating Companies and the Rail Regulator over franchise extensions to encourage investment being just one example.

Our Paper explores a solution to this problem. Recognising that governments may be unable to commit to providing sufficient future profits for investing utilities, it considers the possibility of delegating to an independent regulator with preferences different from its own. If the regulator's track record is sufficiently 'pro-industry', this may encourage the utility's belief that profit will be allowed into the future and, therefore, stimulate investment. It should be noted that the regulator is no more able to commit to particular contracts in the future than the government, but his/her preferences are such that the non-commitment contracts offered are more generous to the firm concerned. An analogy would be with delegation to an independent central bank in monetary policy. Governments unable to commit to anti-inflationary policies appear to have found it useful to delegate to suitably 'hawkish' central bankers whose attitudes to inflation have been sufficiently credible that control has been improved. We argue that, to the extent that regulators enjoy a considerable degree of day-to-day independence, and their attitudes discernible from lengthy public track-records prior to appointment, such delegation may be feasible in a variety of regulatory environments.

Other authors have studied the under-investment effect. In some cases, the level of investment has been taken as observable to the regulator; in others

[1] Newbery, D. (1999): *Privatisation, Restructuring, and Regulation of Network Utilities*, MIT Press: Cambridge, Mass. See Chapter 2.

investment costs have been reimbursed via lump-sum payments by the regulator to the firm; others have assumed an infinitely-lived relationship between regulator and firm (which enables the use of ‘punishment strategies’ to be employed if agreements on investment levels and reimbursement are broken). In this Paper, we make two further contributions by analysing a setting where (i) the regulator cannot observe (or, therefore, contract) upon the level of investment by the firm and (ii) reimbursement is achieved by the regulated prices that the firm is allowed to charge its consumers. Like some features of the delegation we model, it is argued that both of these accurately reflect many real-world features of regulatory settings

We find (via numerical simulation) that delegation to a ‘pro-industry’ regulator can have significant welfare benefits: for some types of regulator, such delegation can be over 90% as good a commitment. Not only is investment encouraged, but the ratchet effect (a common problem in dynamic models with asymmetric information and no commitment) is also reduced by the credible promise of future rent. The range of regulator types for which welfare improves is wide, indicating that there is scope for making a ‘mistake’ when choosing the regulator, yet still producing welfare gains.

Contents

1 Introduction

In many settings, an investment 'hold-up' problem can arise because one party is unable to commit to appropriate action once the other has sunk the investment costs (e.g. Grout (1984)). A familiar example occurs in the context of industry price regulation because regulators face a conflict between their desire to encourage investment and their obligations towards consumers. The weak incentives implicit in such arrangements have been blamed for poor investment performance in several regulatory environments (e.g. Levy and Spiller (1994); Lyon (1995); Newbery (1999)).

The purpose of this paper is to analyse the under-investment problem in the context of a dynamic non-commitment relationship between a regulator and a regulated monopoly. We assume that the regulator observes neither the firm's productivity nor whether investment has taken place, but can observe the firm's total costs (though not the individual components of cost). The presence of asymmetric information means that the welfare costs of suboptimal investment are compounded by those of the ratchet effect that typically afflicts such dynamic non-commitment problems. There are two contributions. First, we propose (and demonstrate) a solution to the under-investment problem based on strategic delegation to an independent regulator with suitable preferences. We suggest that commitment to such 'types' often takes place in practice. Second, we extend the literature on regulation and investment in two other ways. In the first place, situations where the regulator observes neither investment nor the other components of cost has received little attention yet, for some types of activity, is clearly appropriate. In addition, we extend existing literature by examining the problem in the context of optimal (subject to asymmetric information) price regulation, where the regulator is prevented from making lump-sum transfers to the firm. Again, this reflects much regulatory practice.

A number of authors have considered the under-investment problem. The literature can be usefully divided into papers that develop 'reputational' trigger-strategy equilibria where strategies are history-dependent, and those that focus on sequential or perfect Bayesian or subgame-perfect equilibria (depending on the information assumptions) without history-dependence. Considering the former first, in a complete information dynamic game between the utility and a benevolent regulator, Salant and Woroch (1992), and Gilbert and Newbery (1994) (see also Newbery (1999), chapter 2) show that first-best levels of investment can be sustained as a subgame-perfect trigger-strategy equilibrium. Unfortunately, there are well-known problems with this approach. First the length of the punishment phase (usually infinity) is arbitrary and there exists an infinite number of such equilibria, one for each length of punishment. Even if the two players can coordinate on the best of these equilibria, there is a second more serious problem: the equilibrium is not 'renegotiation-proof'. The players always have an incentive to renegotiate after a deviation occurs, rather than carry out the punishment. This questions the credibility of trigger-strategy equilibria, even though they are subgame perfect.[1]

Turning to the second group of papers, Goodwin and Patrick (1992) focus on the speed with which regulators should allow sunk cost recovery. Alternatively, Lyon (1995) uses a full information model to show how allowing the regulator to engage in hindsight review can prevent investment in innovative technology with uncertain costs. Lewis and Sappington (1991) consider the implications for investment caused by changing regulators in a world where investment cost is uncertain but is guaranteed to be reimbursed to the firm. Again, suboptimal investment levels arise (on average, leading to under-investment). Besanko and Spulber (1992) assume that the regulator cannot observe the firm's cost and cannot commit to a particular price level: she must offer a transfer and price once the firm's investment has been observed. In their sequential equilibrium, the firm can signal its type through this observable investment and the under-investment problem is ameliorated; see also Urbiztondo (1994). Dalen (1995) looks at a two-period model in which investment takes place in Period 1. The regulator cannot observe firms' costs and again provides transfers to the firm. When investment is contractible, it reduces the ratchet effect by inducing more first-period separation. When investment is non-contractible, under-investment occurs.[2]

[1] See al Nowaihi and Levine (1994) who, in the context of a monetary policy game, argue for a refinement they term 'chisel-proofness', to resolve this difficulty.

[2] A related literature, beginning with Averch and Johnson (1967) compares investment incentives under alternative forms of price regulation, typically rate-of-return and price-capping. In a recent contribution, allowing for complete information and technical progress, Biglaiser and Riordan (2000) demonstrate that sub-optimal investment may be generated by both these schemes: with rate-of-return

As explained above, we amend this literature by considering a long-term regulatory relationship with non-contractible investment, asymmetric information about costs and no lump-sum transfers. Specifically (like Dalen (1995)) we build on Laffont and Tirole (1993)'s framework. Firms can be efficient or inefficient and can take (costly) action to reduce their costs in each of two periods. In the first, they can also undertake costly activity to lower their costs in future ('investment'). The regulator observes none of these three actions but observes total costs and must design prices to encourage cost-reducing effort and investment, as well as generating consumer surplus. Being unable to commit to future prices means that sub-optimal investment and the ratchet effect occur. We characterise the full range of perfect Bayesian equilibria for this setting, which can involve complete separation as well as partial and complete pooling, and over-investment or under-investment.

Our set-up explores a particular solution to both the ratchet and sub-optimal investment problems using an idea first raised in Currie *et al.* (1999). There it is shown that strategic delegation to an independent regulator with pro-industry preferences can overcome the ratchet effect.[3] The intuition is that a regulator's preference for industry profits dilutes the non-commitment problem she faces. In the current paper, the effects of this idea are particularly strong because the firm's awareness of the regulator's pro-industry tastes makes it more confident of retaining the profits from cost-reducing investment. Thus, such delegation addresses the costs of both commitment problems and we present simulations to illustrate how welfare can be significantly improved as a result.[4]

regulation this happens because of the treatment of depreciation in the face of technical progress; with price-capping it results from the commitment problems associated with regulatory reviews.

[3]Baron and Besanko (1987) consider a related idea, where the regulator chooses from 'fair' mechanisms (those which respect the firm's zero profit constraint). Unlike the current paper, there is no delegation or moral hazard, and 'fair' regulation requires courts to be able to observe and monitor 'regulatory contracts' and firms' responses.

[4]It should be noted that the literature identifies several kinds of strategic delegation. In particular, apart from delegation to a (publicly observable) 'type' of regulator (Baron (1988), Spulber and Besanko (1992), Currie *et al.* (1999)) one might consider delegation to a given regulator whose actions are then governed by an incentive contract or set of instructions which may (or may not) be publicly observable—see Fershtman *et al.* (1991), Fershtman and Kalai (1997) and interesting experimental work in Fershtman and Gneezy (2001). Analogously, literature on central banking also distinguishes these two kinds of strategic delegation: see Rogoff (1985) for delegation to types of bankers and Walsh (1995), for delegation with incentive contracts. The key ingredient is that observable commitment (to a type, a contract, an instruction or to the use of delegation), can improve welfare from the delegator's

We argue that this solution is appealing because of its correspondence with practice in several economies: for example, utilities regulation in the UK and certain features of environmental regulation in the US. One of the arguments used in favour of regulation over public ownership has been the independence this injects into the oversight of the industries concerned (Armstrong *et al.* (1994)) and it is certainly the case that British regulators are contractually independent from considerable government interference.[5] Further, it is also clear that different 'types' of regulator are available to a government and that these types are observable before appointment (for example, from the candidate's track-record).[6] Thus, it seems to be the case that a government can commit to a particular type of regulator, more easily than to a particular policy. This point has also been made by Spulber and Besanko (1992) in the context of US environmental regulation and by Rogoff (1985), in the context of monetary policy.

The paper is structured as follows. In the next section, we set out the basic model and derive our first benchmark: the Ramsey optimum prices and investment levels. Section 3 then looks at price regulation with asymmetric information and commitment to two-period contracts, in order to provide a benchmark against which we can compare the non-commitment outcome. In Section 4, we relax the commitment assumption and, instead, introduce the idea of strategic delegation to a regulator whose 'type' is observable *ex ante*. We then characterise the full set of equilibria for this model and illustrate them by simulation. Of particular interest here is the potential increases in investment and Pareto improvements in welfare that come about through delegation and the wide range of regulator types capable of achieving this outcome. The final section offers conclusions and suggestions for further research.

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perspective.

[5]This point has recently received media attention in the context of UK telecommunications regulation. For example: "...the [BT regulator] is officially independent of ministerial control and ...is not due for reappointment for another three years" (Financial Times, 22/9/00, p. 1). See Graham (2000) for an account of the constitutional status of utility regulators in the UK.

[6]Again, examples are available in the UK. Thus, Tom Winsor's appointment as UK rail regulator in 1999 was regarded as a "hawkish" move amongst commentators because of his strong track record in consumer law (e.g. Daily Telegraph, 24/3/99; 28/5/99). We do not consider the mechanisms available for choosing such regulators (see Baron (1988), Spulber and Besanko (1992), for examples of how the political process might do this). Instead, our aim is to illustrate the gains available from such delegation in the current context.

2 The Set-up and the Ramsey Optimum

2.1 The Model and Payoffs

First, we set out the basic elements of the delegation game. There are two periods. In period $t = 1, 2$, the firm produces a quantity q_t of a homogeneous good at cost

$$C_t = \beta_t - e_t + cq_t; \quad \beta_1 = \beta + i; \quad \beta_2 = \beta - f(i) \tag{1}$$

where e_t is total cost-reducing effort of which an amount i, investment, is devoted to reducing fixed costs in the second period by an amount $f(i)$.[7] Marginal costs are fixed and given by c. We assume $f' > 0, f'' < 0,\ f(0) = 0, f'(0) = -\infty$. We also assume that the efficiency parameter is sufficiently large to ensure that fixed costs are never negative; i.e., in all equilibria, $\beta_t - e_t \geq 0$. The good is sold at a price $p_t = \phi(q_t)$ where $\phi(\cdot)$ is the inverse demand curve.

Both the firm and regulator maximize a two-period welfare function with the same discount factor δ and with single-period payoffs given respectively by

$$\begin{aligned} U(q_t, e_t, \beta_t) &= R(q_t) - C_t - \psi(e_t) \\ &= R(q_t) - cq_t - \beta_t + e_t - \psi(e_t) \qquad (2) \\ W(q_t, e_t, \beta_t, \alpha) &= S(q_t) - R(q_t) + \alpha U_t \\ &= S(q_t) - (1-\alpha)R(q_t) - \alpha[cq_t + (\beta_t - e_t + \psi(e_t))] \qquad (3) \end{aligned}$$

In (2), $\psi(e_t)$ is the disutility of effort. We assume ψ', $\psi'' > 0$ for $e_t > 0$, $\psi(e_t) = 0$ otherwise. In (3), $S(q_t)$ is the gross consumer surplus of the industry, $R(q_t) = p_t q_t$ is the revenue, where p_t is the price, $S(q_t) - R(q_t)$ is the net consumer surplus and the weight α is the weight placed on the firm's profit by the regulator. A utilitarian regulator would have $\alpha = 1$, but in this paper we examine the effect of delegating

[7]Note that effort only reduces fixed and not variable costs, an assumption that can be relaxed at a considerable cost in terms of tractability. For example we could assume two types of effort which are imperfect substitutes with managers dividing their total effort in each period between reducing fixed and variable costs. Laffont and Tirole (1993) consider situations where all effort is devoted to reducing variable costs.

to a regulator chosen to have different preferences. Suppose that the government has preferences defined by $\alpha = \alpha_s \leq 1$. Then a choice $\alpha > \alpha_s$ signifies a more 'pro-industry' (pro-rent) regulator type than the government, while $\alpha < \alpha_s$ would signify a more 'pro-consumer' type.

2.2 The Ramsey Optimum (RO)

We first solve for the 'Ramsey Optimum'; that is the social optimum subject to a two-period individual rationality constraint for the firm. Suppose that the social planner adopts the single-period social welfare function (3) with weight $\alpha = \alpha_s$. Then the RO is found by the maximization of the intertemporal social welfare function $\Omega = W_1 + \delta W_2$ with respect to $(q_t,\, e_t)$, $t = 1, 2$ and i, where W_t is given by (3) with weight $\alpha = \alpha_s$, subject to a two-period individual rationality constraint

$$IR : U_1 + \delta U_2 \geq 0$$

To solve this maximization problem define a Lagrangian $\mathcal{L} = \Omega + \mu(U_1 + \delta U_1)$ where μ is a Lagrangian multiplier. The Kuhn-Tucker first-order conditions are

$$\begin{aligned} e_t &: \quad \psi'(e_t) = 1; \quad t = 1, 2 && (4) \\ i &: \quad \delta f'(i) = 1 && (5) \\ q_t &: \quad S'(q_t) + (\alpha_s - 1 + \mu)R'(q_t) = (\alpha_s + \mu)c; \quad t = 1, 2 && (6) \\ CS &: \quad \mu(U_1 + \delta U_2) = 0 \end{aligned}$$

where CS is the complementary slackness condition. Using the standard result $S'(q_t) = p_t$, (6) can be written

$$L_t = \frac{p_t - c}{p_t} = \frac{\mu + \alpha_s - 1}{(\mu + \alpha_s)\eta(q_t)} \tag{7}$$

where L_t is the Lerner index and $\eta(q_t) = -p_t q_t'/q_t$ is the elasticity of demand. It follows from (7) that the price in each period is the same. Furthermore, since fixed costs can never be negative by assumption, this common price must exceed the marginal cost, otherwise the IR constraint cannot be satisfied. It follows that $L_t > 0$. Also note that $L_t < 1/\eta$, the latter upper bound being the mark-up under monopoly pricing. It follows from (7) that $\mu > 0$, and the IR condition therefore binds, iff

$$L_t = \frac{p_t - c}{p_t} \geq \frac{\alpha_s - 1}{\alpha_s \eta(q_t)}; \quad t = 1, 2$$

Clearly this condition holds if $\alpha_s \leq 1$, which we assume.

¿From (7) Ramsey prices $p_1 = p_2 = p^{RO}$ and hence output $q_1 = q_2 = q^{RO}$ are equal in the two periods, but not yet determined. Denote by e^{RO} and i^{RO} the Ramsey-optimal levels of e and i given by (4) and (5) respectively. Substituting back into the binding IR constraint then determines the Ramsey-optimal output q^{RO} and hence the price $p^{RO} = \phi(q^{RO})$, completing the social planner's problem. It is straightforward to show that the RO can also be attained if the regulator continues to have complete information about the cost and demand structure, and can commit to a two-period contract that specifies *only* the price, p^{RO}, in each. Neither short-term cost-reducing effort $(e - i)$ nor long-term cost-reducing effort (i), i.e., 'investment', need to be observed or regulated; rent-maximizing managers will choose the Ramsey-optimal level of both types of effort, given the price.

3 Asymmetric Information with Commitment

Now suppose that neither effort nor the productivity parameter β are observed by the regulator so she faces both an adverse selection and moral hazard problem. The regulator observes total cost and knows that β belongs to a two-point support: $\beta = \underline{\beta}$ and $\beta = \overline{\beta}$ $(\overline{\beta} > \underline{\beta} > 0)$, over which she holds priors ν_1 and $1 - \nu_1$ respectively at the beginning of period 1. For this section only, we assume that investment is contractible since it is straightforward to show that the same cost-contingent contracts will result in the same investment and output levels when this assumption is relaxed, but commitment remains feasible.

3.1 Contracts with Credible Commitment

The regulator designs a two-period contract linking the regulated price to cost in each period, $(\underline{p}_t, \underline{C}_t), (\overline{p}_t, \overline{C}_t), t = 1, 2$, and specifies investments $(\underline{i}, \overline{i})$ for the efficient and inefficient firms respectively. These cost and investment levels are achieved by exerting total effort $(\underline{e}_t, \overline{e}_t)$ for the two types. In each period $t = 1, 2$, the efficient firm can then mimic the inefficient type, receive a regulated price $\overline{p}_t$, and produce at the higher cost $\overline{C}_t$ by exerting effort $\underline{\tilde{e}}_t = \overline{e}_t - \Delta\beta$ where $\Delta\beta = \overline{\beta} - \underline{\beta}$.[8] Then the efficient firm's mimicking rent is given by

$$\underline{\tilde{U}}_t = \overline{p}_t \overline{q}_t - \overline{C}_t - \psi(\underline{\tilde{e}}_t) = \overline{U}_t + \Phi(\overline{e}_t)$$

where $\Phi(\overline{e}_t) = \psi(\overline{e}_t) - \psi(\overline{e}_t - \Delta\beta)$ is the *informational rent* at time t; i.e., the extra rent the efficient type obtains from mimicking the inefficient type. Since $\Phi'(\overline{e}_t) = \psi'(\overline{e}_t) - \psi'(\overline{e}_t - \Delta\beta)$ and $\psi'' > 0$, we have that $\Phi'(\overline{e}_t) > 0$. Thus we have the familiar trade-off for incentive contracts: the higher the effort of the inefficient type of firm, the higher the rent the efficient type requires to prevent it from mimicking. Similarly the inefficient firm can mimic the efficient firm and produce at the lower cost $\underline{C}_t$ by exerting effort $\tilde{\overline{e}}_t = \underline{e}_t + \Delta\beta$, this time at a cost in terms of rent of $\Phi(\tilde{\overline{e}}_t)$. Incentive compatibility (IC) and individual rationality (IR) constraints are now:

$$\begin{aligned}
\underline{IC}: &\quad \underline{U}_1 + \delta\underline{U}_2 \geq \underline{\tilde{U}}_1 + \delta\underline{\tilde{U}}_2 = \overline{U}_1 + \delta\overline{U}_2 + \Phi(\overline{e}_1) + \delta\Phi(\overline{e}_2) \\
\overline{IC}: &\quad \overline{U}_1 + \delta\overline{U}_2 \geq \tilde{\overline{U}}_1 + \delta\tilde{\overline{U}}_2 = \underline{U}_1 + \delta\underline{U}_2 - \Phi(\tilde{\overline{e}}_1) - \delta\Phi(\tilde{\overline{e}}_2) \\
\overline{IR}: &\quad \overline{U}_1 + \delta\overline{U}_2 \geq 0 \\
\underline{IR}: &\quad \underline{U}_1 + \delta\underline{U}_2 \geq 0
\end{aligned}$$

Clearly, $\underline{IC} + \overline{IR} \Rightarrow \underline{IR}$, so we can drop the latter constraint. The regulator's optimization problem is now:

Given ν_1, $\underline{\beta}$, $\overline{\beta}$, choose $(\overline{q}_t, \overline{e}_t)$, $(\underline{q}_t, \underline{e}_t)$, $t = 1, 2$, and $(\overline{i}, \underline{i})$ to maximize the ex-

[8] Throughout the paper we adopt the following notation: $\underline{\tilde{z}}$ is some outcome for the efficient firm who mimics the inefficient firm and $\tilde{\overline{z}}$ is the corresponding outcome for the inefficient firm who mimics the efficient firm.

pected welfare

$$\Omega = \sum_{t=1}^{2} \delta^{t-1}[\nu_1 W(\underline{q}_t, \underline{e}_t, \underline{\beta}_t, \alpha_s) + (1-\nu_1) W(\overline{q}_1, \overline{e}_t, \overline{\beta}_t, \alpha_s)]$$

subject to the constraints $\underline{IC}$, $\overline{IC}$ **and** $\overline{IR}$**.**

To solve this optimization problem, define a Lagrangian

$$\begin{aligned}
\mathcal{L} &= \Omega + \mu[\underline{U}_1 + \delta \underline{U}_2 - \overline{U}_1 - \delta \overline{U}_2 - \Phi(\overline{e}_1) - \delta \Phi(\overline{e}_2)] \\
&+ \zeta[\overline{U}_1 + \delta \overline{U}_2 - \underline{U}_1 - \delta \underline{U}_2 + \Phi(\tilde{\underline{e}}_1) + \delta \Phi(\tilde{\underline{e}}_2)] + \xi[\overline{U}_1 + \delta \overline{U}_2]
\end{aligned}$$

where $\mu \geq 0$, $\zeta \geq 0$ and $\xi \geq 0$ are Lagrangian multipliers associated with the constraints $\underline{IC}$, $\overline{IC}$ and $\overline{IR}$ respectively, which the regulator maximizes with respect to $\overline{q}_t$, $\underline{q}_t$, $\overline{e}_t$, $\underline{e}_t$; $t = 1, 2$, $\underline{i}$ and $\overline{i}$. The first order conditions are:

$$\begin{aligned}
\underline{L}_t = \frac{\underline{p}_t - c}{\underline{p}_t} &= \frac{\mu - \zeta + \nu_1(\alpha - 1)}{(\mu - \zeta + \nu_1 \alpha)\eta(\underline{q}_t)} && (8) \\
\overline{L}_t = \frac{\overline{p}_t - c}{\overline{p}_t} &= \frac{\xi - \mu + \zeta + (1-\nu_1)(\alpha - 1)}{(\xi - \mu + \zeta + (1-\nu_1)\alpha)\eta(\overline{q}_t)} && (9) \\
(\nu_1 \alpha + \mu - \zeta)(1 - \psi'(\underline{e}_t)) &= -\zeta \Phi'(\underline{e}_t + \Delta\beta)) && (10) \\
((1-\nu_1)\alpha + \xi - \mu + \zeta)(1 - \psi'(\overline{e}_t)) &= \mu \Phi'(\overline{e}_t)) && (11)
\end{aligned}$$

for $t = 1, 2$, plus the complementary slackness conditions:

$$\mu \sum_{t=1}^{2} \delta^{t-1}[\underline{U}_t - \overline{U}_t - \Phi(\overline{e}_t)] = \zeta \sum_{t=1}^{2} \delta^{t-1}[\overline{U}_t - \underline{U}_t + \Phi(\overline{e}_t + \Delta\beta_t)] = \xi \sum_{t=1}^{2} \delta^{t-1} \overline{U}_t = 0 \quad (12)$$

and the optimality conditions for investment:

$$(\alpha \nu_1 + \mu - \zeta)[-1 + \delta f'(\underline{i})] = (\alpha(1-\nu_1) + \xi - \mu + \zeta)[-1 + \delta f'(\overline{i})] = 0 \quad (13)$$

This results in prices $\underline{p}_t^C, \overline{p}_t^C$, effort $\underline{e}_t^C, \overline{e}_t^C$, rents $\underline{U}_t^C, \overline{U}_t^C$, $t = 1, 2$ and investment $\underline{i}^C, \overline{i}^C$. From the Lerner indices (8) and (9) it is immediately apparent that output, prices and effort specified for each type are constant over the two periods. Let $\underline{p}_1^C = \underline{p}_2^C = \underline{p}^C$,

$\overline{p}_1^C = \overline{p}_2^C = \overline{p}^C$, etc. Then we can show[9]

Proposition 1. *Assume $\alpha = \alpha_s \leq 1$ and fixed costs are always positive. Then for the two-period contract under commitment we have that:*
(i) $\overline{IC}$ does not bind ($\zeta = 0$), $\overline{IR}$ and $\underline{IC}$ do bind and $\xi > \mu > 0$.
(ii) $\underline{e}^C = e^{RO}$; $\overline{e}^C = \overline{e}^C < e^{RO}$.
(iii) $\underline{i}^C = \overline{i}^C = i^{RO}$.
(iv) If the elasticity $\eta(q_t)$ is non-increasing in q_t, $\overline{p}^C > \underline{p}^C$.
(v) For both types of firm, rent is less in the first period than the second. For the inefficient firm, rent is negative in the first period and positive in the second.

Apart from investment which is Ramsey-optimal and which lowers first-period and raises second-period rent, the commitment solution has the same features as single-period incentive contracts. The efficient type receives discounted rent over the two periods and exerts socially optimal levels of effort; the inefficient type receives no discounted two-period rent and exerts effort below the optimal. The information rent received by the efficient type is an increasing function of the inefficient type's effort and this trade-off facing the regulator is the reason that the optimal contract entails sub-optimal levels of effort by the inefficient type.

3.2 The Credibility Problem

We have seen that if the regulator can make a credible binding commitment to a two-period contract ($\underline{p}^C$, $\underline{C}_1$), ($\underline{p}^C$, $\underline{C}_2$) and ($\overline{p}^C, \overline{C}_1$), ($\overline{p}^C, \overline{C}_2$) for the efficient and inefficient firm respectively, where $\underline{C}_1$, $\underline{C}_2$, $\overline{C}_1$ and $\overline{C}_2$ are found by substituting (ii) and (iii) from Proposition 1 into (1), then regardless of whether investment is contractible, each type will choose the contract designed for itself resulting in levels of effort, investment and rents given in Proposition 1. However the contract is *time-inconsistent*: although it is optimal *ex ante*, *ex post* in period 2 it ceases to be optimal and there exists a temptation for the regulator to re-optimize. This temptation exists for two reasons. First, the contract is a revelation mechanism that reveals the type of firm. In the

[9]Where propositions do not follow from the text, proofs are provided in the Appendix.

second period an optimizing regulator will offer a new contract at a lower price that removes any information rent to the efficient firm. This is the familiar 'ratchet effect' which, when anticipated by the efficient firm, leads to higher information rent in the first period to satisfy the first-period incentive-compatibility constraint. Second, the first-period investment is a sunk-cost. The *ex ante* contract sees negative rent in the first period and positive rent in the second period for both types. However, in the absence of a binding commitment, *ex post* an optimizing regulator will renege on the promise of positive rent and offer a new contract at a lower price just sufficient to satisfy the second-period individual rationality constraint. Anticipating this opportunistic behaviour both firms will under-invest in the first period. The next section analyzes the equilibrium without commitment and shows that the extent, or indeed the existence, of this under-investment depends on the nature of the asymmetric information between the firm and the regulator and on the type of regulator.

4 Asymmetric Information without Commitment

4.1 The Delegation Game

We now consider a two-period, two-type delegation game with the same structure and information assumptions as section 3, but now we relax the assumption that the regulator can commit to a two-period price contract. The government however can commit to a particular regulator over this interval.[10] Asymmetric information introduces dynamics through the process of learning about the firm's type. At the beginning of the game the firm knows its type β. The government and all types of regulators have the prior ν_1 that $\beta = \underline{\beta}$. Then the sequence of events for the delegation game is given by:

1. The government has preferences as for the regulator, except that rent carries a weight α_s (reflecting social welfare), and delegates to an independent regulator of type $\alpha \neq \alpha_s$ for the two periods. In the absence of delegation, the regulator is government-dependent and adopts a weight $\alpha = \alpha_s$.

[10] In common with much of the strategic delegation literature, we do not examine the reasons why a government may find it easier to commit to a type of regulator than (say) to a pricing policy: our intention is to demonstrate the effects that such delegation can have on investment and welfare.

2. The regulator offers a choice of two first-period price contracts from which the firm chooses one or neither.

3. The regulator updates her prior ν_1 to ν_2.

4. First-period effort e_1 and investment i are applied by the firm, the cost C_1 and output (and price) are realized and observed by regulator.

5. The regulator offers a choice of two second-period contracts from which the firm chooses one or neither.

6. Second-period effort e_2 is applied by the firm, the cost C_2 and output (and price) are realized and observed by regulator.

In the first period, given ν_1, the regulator designs contracts $(\underline{p}_1, \underline{C}_1)$ and $(\overline{p}_1, \overline{C}_1)$. In general we must consider equilibria in which the efficient firm may mimic the inefficient and *vice versa*. When the efficient firm chooses the low cost contract it chooses output $\underline{q}_1 = \phi^{-1}(\underline{p}_1)$ and effort $(\underline{e}_1, \underline{i})$ such that observed cost $\underline{C}_1 = \underline{\beta} - \underline{e}_1 + \underline{i} + c\underline{q}_1$. Similarly when the inefficient firm chooses the high cost contract it chooses output $\overline{q}_1 = \phi^{-1}(\overline{p}_1)$ and effort $(\overline{e}_1, \overline{i})$ such that observed cost $\overline{C}_1 = \overline{\beta} - \overline{e}_1 + \overline{i} + c\overline{q}_1$. Denote mimicking effort for the efficient and inefficient firms by $(\tilde{\underline{e}}_1, \tilde{\underline{i}})$ and $(\tilde{\overline{e}}_1, \tilde{\overline{i}})$. In order to realize the appropriate observed costs, these mimicking efforts must satisfy

$$\tilde{\underline{e}}_1 = \overline{e}_1 - \Delta\beta + \tilde{\underline{i}} - \overline{i}\,; \quad \tilde{\overline{e}}_1 = \underline{e}_1 + \Delta\beta + \tilde{\overline{i}} - \underline{i} \tag{14}$$

Suppose that the efficient firm chooses the low cost contract with probability x and the high cost contract with probability $1 - x$. Similarly suppose that the inefficient firm chooses the high cost contract with probability y and the low cost contract with probability $1 - y$. The appropriate equilibrium concept for this game is a Perfect Bayesian Equilibrium (PBE) found by backward induction starting at event 5. We define the regulator's information sets at this point as follows: H (resp. L) if $(\overline{p}_1, \overline{C}_1)$ (resp. $(\underline{p}_1, \underline{C}_1)$) was accepted in period 1.

4.2 The Second-Period Contract

At L and H, the regulator designs contracts $(\underline{p}_2, \underline{C}_2)$, and $(\overline{p}_2, \overline{C}_2)$ for low and high cost types respectively, given the (updated) probabilities $\nu_2(L)$ and $\nu_2(H)$ that the firm is efficient. At L we have that $\underline{\beta}_2 = \underline{\beta} - f(\underline{i})$ and $\overline{\beta}_2 = \overline{\beta} - f(\tilde{\underline{i}})$. Similarly at H we have that $\underline{\beta}_2 = \underline{\beta} - f(\tilde{\overline{i}})$ and $\overline{\beta}_2 = \overline{\beta} - f(\overline{i})$. It is convenient to formulate the regulator's problem in terms of the choice of output and effort levels bearing in mind that contracts are designed as prices, contingent on observed total costs. The regulator's problem, to be carried out at each information set characterized by the state variables given by the vector $s = [\nu_2, \underline{\beta}_2, \overline{\beta}_2]$, is now:

Given $s = [\nu_2, \underline{\beta}_2, \overline{\beta}_2]$, choose $(\overline{q}_2, \overline{e}_2)$ and $(\underline{q}_2, \underline{e}_2)$ to maximize the expected welfare

$$E[W_2] = \Omega_2 = \nu_2 W(\underline{q}_2, \underline{e}_2, \underline{\beta}_2, \alpha) + (1 - \nu_2) W(\overline{q}_2, \overline{e}_2, \overline{\beta}_2, \alpha) \tag{15}$$

subject to $\underline{IC}_2$, $\overline{IC}_2$ and $\overline{IR}_2$.

By analogy with section 3 these constraints can be written as:

$$\begin{aligned}
\underline{IC}_2 : \quad & \underline{U}_2 \geq \tilde{\underline{U}}_2 = \overline{U}_2 + \Phi(\overline{e}_2) \\
\overline{IC}_2 : \quad & \overline{U}_2 \geq \tilde{\overline{U}}_2 = \underline{U}_2 - \Phi(\underline{e}_2 + \Delta\beta_2) \\
\overline{IR}_2 : \quad & \overline{U}_2 \geq 0 \\
\underline{IR}_2 : \quad & \underline{U}_2 \geq 0
\end{aligned}$$

and as before, $\underline{IC}_2 + \overline{IR}_2 \Rightarrow \underline{IR}_2$, so we can drop the latter constraint.

To solve this optimization problem, let $\mu_2 \geq 0$, $\zeta_2 \geq 0$ and $\xi_2 \geq 0$ be the Lagrangian multipliers associated with the $\underline{IC}_2$, $\overline{IC}_2$ and $\overline{IR}_2$ constraints respectively. Then defining the Lagrangian

$$\mathcal{L}_2 = \Omega_2 + \mu_2(\underline{U}_2 - \overline{U}_2 - \Phi(\overline{e}_2)) + \zeta_2(\overline{U}_2 - \underline{U}_2 + \Phi(\underline{e}_2 + \Delta\beta_2)) + \xi_2 \overline{U}_2$$

the first-order conditions are:

$$\underline{L}_2 = \frac{\underline{p}_2 - c}{\underline{p}_2} = \frac{\mu_2 - \zeta_2 + \nu_2(\alpha - 1)}{(\mu_2 - \zeta_2 + \nu_2\alpha)\eta(\underline{q}_2)} \tag{16}$$

$$\overline{L}_2 = \frac{\overline{p}_2 - c}{\overline{p}_2} = \frac{\xi_2 - \mu_2 + \zeta_2 + (1 - \nu_2)(\alpha - 1)}{(\xi_2 - \mu_2 + \zeta_2 + (1 - \nu_2)\alpha)\eta(\overline{q}_2)} \tag{17}$$

$$\begin{aligned}
(\nu_2\alpha + \mu_2 - \zeta_2)(1 - \psi'(\underline{e}_2)) &= -\zeta_2\Phi'(\underline{e}_2 + \Delta\beta_2) \\
((1 - \nu_2)\alpha + \xi_2 - \mu_2 + \zeta_2)(1 - \psi'(\overline{e}_2)) &= \mu_2\Phi'(\overline{e}_2) \\
\mu_2(\underline{U}_2 - \overline{U}_2 - \Phi(\overline{e}_2)) &= 0 \qquad (18) \\
\zeta_2(\overline{U}_2 - \underline{U}_2 + \Phi(\overline{e}_2 + \Delta\beta_2)) &= 0 \\
\xi_2\overline{U}_2 &= 0
\end{aligned}$$

By analogy with Proposition 1(i) we now can show:

Proposition 2. *For a utilitarian or pro-consumer regulator ($\alpha \leq 1$), in Period 2 we have that the $\overline{IC}_2$ constraint does not bind ($\zeta_2 = 0$), but the $\underline{IC}_2$ and $\overline{IR}_2$ constraints do bind with $\xi_2 > \mu_2 > 0$.*

This, of course, is the familiar result for a single-period model (see Laffont and Tirole (1993)). However, we are now able to see what happens as α increases beyond 1 (i.e. as the regulator becomes increasingly pro-industry). We find that three second period equilibria can emerge, depending on α, and denote these as b, c and d. (An equilibrium denoted a is introduced when we consider the first period analysis.)

Second-Period Equilibrium b: $\alpha \in [1, \underline{\alpha}_2]$. Only $\underline{IC}_2$ and $\overline{IR}_2$ constraints bind. We know from Proposition 3 that this range of α exists. Putting $\zeta_2 = 0$ and eliminating μ_2 and ξ_2 the first order conditions for this equilibrium become

$$\begin{aligned}
\underline{U}_2 &= U(\underline{q}_2, \underline{e}_2, \underline{\beta}_2) = \Phi(\overline{e}_2) \qquad (19) \\
\overline{U}_2 &= U(\overline{q}_2, \overline{e}_2, \overline{\beta}_2) = 0 \\
\psi'(\underline{e}_2) &= 1; \quad i.e., \ \underline{e}_2 = e^{RO} \\
\frac{(1 - \nu_2)}{(1 - \eta(\overline{q}_2)\overline{L}(\overline{q}_2))}(1 - \psi'(\overline{e}_2)) &= \nu_2 \left[\frac{1}{(1 - \eta(\underline{q}_2)\underline{L}(\underline{q}_2))} - \alpha \right] \Phi'(\overline{e}_2) \qquad (20)
\end{aligned}$$

which gives four equations in $\underline{q}_2, \overline{q}_2, \underline{e}_2$ and $\overline{e}_2$. We can now prove:

Proposition 3. *In second-period equilibrium b we have:*

(i) If $\eta(q_t)$ is non-increasing then $\underline{p}_2 < \overline{p}_2$ (implying $\underline{L}_2 < \overline{L}_2$ and $\underline{q}_2 > \overline{q}_2$).

(ii) $\frac{d\overline{e}_2}{d\alpha} > 0$; $\frac{d\underline{q}_2}{d\alpha} < 0$; $\frac{d\overline{q}_2}{d\alpha} > 0$; $\frac{d\underline{L}_2}{d\alpha} > 0$; $\frac{d\overline{L}_2}{d\alpha} < 0$.

(iii) Assume $e^{RO} > \Delta\beta_2$. Then as α increases, first $\underline{IC}_2$ ceases to bind ($\mu_2 = 0$) at $\alpha = \underline{\alpha}_2$ and then $\overline{IR}_2$ ceases to bind too, at $\alpha = \overline{\alpha}_2$, say.

The intuition is as follows. Since $\overline{p}_2 > \underline{p}_2$ there is no incentive for the inefficient type to mimic the efficient type. Therefore constraint $\overline{IC}_2$ does not bind. The following possibilities remain: $\underline{IC}_2$ and $\overline{IR}_2$ bind (i.e., equilibrium b), only $\underline{IC}_2$ binds, only $\overline{IR}_2$ binds, and no constraints bind. Of these, an equilibrium with only $\underline{IC}_2$ binding must be sub-optimal because it implies rent for the inefficient type which must also be passed on to the efficient type. As α increases, Proposition 3(iii) tells us that the increasingly generous regulator provides enough rent to stop the efficient firm from mimicking, then to allow the inefficient firm positive rent. These possibilities are characterised in our remaining second-period equilibria:

Second-Period Equilibrium c: $\alpha \in (\underline{\alpha}_2, \overline{\alpha}_2]$. Only $\overline{IR}_2$ binds.

$$\underline{L}_2 = \frac{\underline{p}_2 - c}{\underline{p}_2} = \frac{\alpha - 1}{\alpha\eta(\underline{q}_2)} \tag{21}$$

$$\overline{U}_2 = U(\overline{q}_2, \overline{e}_2, \overline{\beta}_2) = 0 \tag{22}$$

$$\psi'(\overline{e}_2) = \psi'(\underline{e}_2) = 1; \, i.e., \overline{e}_2 = \underline{e}_2 = e^{RO} \tag{23}$$

$$\underline{U}_2 > \overline{U}_2 + \Phi(\overline{e}_2) \tag{24}$$

Second-Period Equilibrium d: $\alpha > \overline{\alpha}_2$. Unconstrained.

$$\underline{L}_2 = \frac{\underline{p}_2 - c}{\underline{p}_2} = \frac{\alpha - 1}{\alpha\eta(\underline{q}_2)} \tag{25}$$

$$\overline{L}_2 = \frac{\overline{p}_2 - c}{\overline{p}_2} = \frac{\alpha - 1}{\alpha\eta(\overline{q}_2)} \tag{26}$$

$$\overline{U}_2 > 0 \tag{27}$$

$$\psi'(\overline{e}_2) = \psi'(\underline{e}_2) = 1; \, i.e., \overline{e}_2 = \underline{e}_2 = e^{RO} \tag{28}$$

$$\underline{U}_2 > \overline{U}_2 + \Phi(\overline{e}_2) \tag{29}$$

Figure 1 illustrates Proposition 3 for functional forms and parameter values discussed before the main numerical results in section 4.7.[11] The Lerner indices for the two types and effort for the inefficient type are plotted. The latter should be compared with effort by the efficient type which is the Ramsey optimum (equal to unity for our chosen parameters).[12] In Figure 1 all the predictions of Proposition 3 are confirmed with $\underline{\alpha}_2 \approx 1.475$ and $\overline{\alpha}_2 \approx 1.525$.

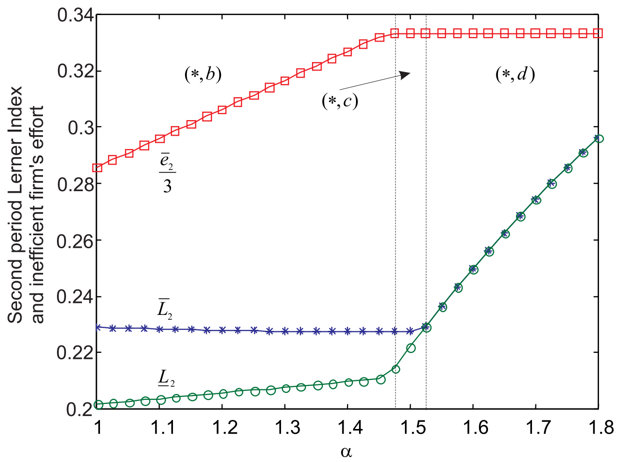

Figure 1: Second period Lerner Indices and inefficient firm's effort

4.3 The Investment Decision

Consider a firm of either type who has accepted a first-period contract specifying price and cost, (p_1, C_1), and faces the prospect of a rent $U_2 = U(q_2, e_2, \beta_2)$ corresponding to one of the second-period equilibria b, c or d at L or H. From the second-period optimization we know that (q_2, e_2) is a function of the state vector $s = [\nu_2, \underline{\beta}_2, \overline{\beta}_2]$ at the relevant information set. Thus we can write $U_2 = U_2(s)$. Then given (p_1, C_1) and therefore $q_1 = \phi^{-1}(p_1)$, the firm chooses i to maximize

$$U_1 + \delta U_2 = p_1 q_1 - C_1 - \psi(\beta + i + cq_1 - C_1) + \delta U_2(\beta_2(i)) \tag{30}$$

[11]Our notation $(*, b)$ etc. in Figure 1 refers to the three possible second-period equilibria. The '$*$' indicates the associated first-period equilibria, which we characterise in section 4.5.

[12]In fact the figure plots $\overline{e}_2/3$ to make the Lerner indices and effort of comparable scale.

The first-order condition for a local maximum is

$$\psi'(\beta + i + cq_1 - C_1) = \psi'(e_1) = -\delta \frac{\partial U_2}{\partial \beta_2} f'(i) \tag{31}$$

using $\beta_2 = \beta - f(i)$, from which $\beta_2'(i) = -f'(i)$. This is the familiar condition that the marginal cost of investment ($MC(e_1) = \psi'(e_1)$) must equal its marginal benefit ($MB(i)$). Write the solution to (31) as $i = i(e_1)$. Since a change in β_2 can result in a shift to a new second-period equilibrium (e.g., type b to type c or d), we must consider the possibility that $i = i(e_1)$ is only a local equilibrium and is sub-optimal compared with no investment. Thus given e_1, the investment decision is $i = i(e_1)$ if $-\psi(e_1) + \delta U_2(\beta_2(i)) > -\psi(e_1 - i)) + \delta U_2(\beta_2(0))$ and $i = 0$, otherwise. Assuming this condition is satisfied, we can differentiate (31) to obtain

$$\psi''(e_1) = -\delta \left[\frac{\partial U_2}{\partial \beta_2} f''(i) - \frac{\partial^2 U_2}{\partial {\beta_2}^2} (f'(i))^2 \right] \frac{di}{de_1} \tag{32}$$

Hence we have the following result and proposition:

$$\frac{di}{de_1} < 0 \text{ provided that } \left[\frac{\partial U_2}{\partial \beta_2} f''(i) - \frac{\partial^2 U_2}{\partial {\beta_2}^2} (f'(i))^2 \right] > 0 \tag{33}$$

Proposition 4. *There is an investment-effort trade-off in the first period and more investment can only be secured at the expense of lower effort (i.e., a lower power contract) in the first period, provided the condition in* (33) *is satisfied. Over-investment or under-investment can occur.*

Stated differently, the condition in (33) is that $MB(i) = -\delta \frac{\partial U_2}{\partial \beta_2} f'(i)$ is decreasing in i.[13] The optimal investment where $\psi'(e_1) = 1$ and $\frac{\partial U_2}{\partial \beta_2} = -1$ is given by the intersection of optimal MC and MB curves in Figure 2. Figure 2a shows a sub-optimal MB curve with $| \frac{\partial U_2}{\partial \beta_2} |< 1$ to the left of its optimal counterpart, accompanied by a lower power contract and therefore a lower MC curve that results in *under-investment* compared

[13]For small changes in $\underline{\beta}_2$ and $\overline{\beta}_2$ we can linearise $U_2(s)$ around $\underline{\beta}$ and $\overline{\beta}$, the second term in this condition can be ignored and the condition becomes $\frac{\partial U_2}{\partial \beta_2} f''(i) > 0$. Since $f'' < 0$ and $\frac{\partial U_2}{\partial \beta_2} < 0$ is necessary for any investment, the condition then holds. We are not able to show that the condition holds more generally, but numerical results seem to indicate that this may be the case.

with the Ramsey optimum. In Figure 2b the downward shift in the MC line relative to a smaller leftward shift in the MB is sufficient to result in *over-investment.*

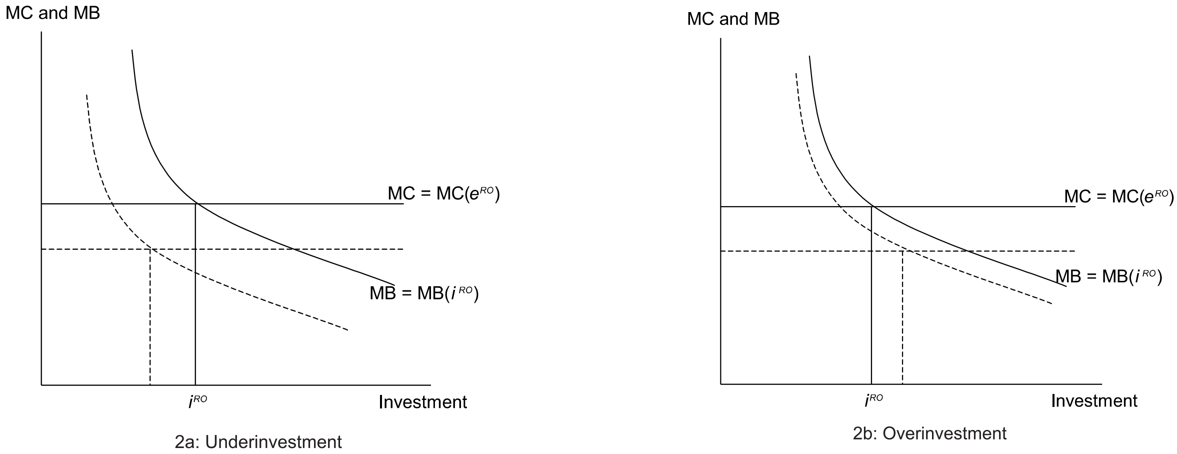

Figure 2: Determinants of under/over-investment

Now consider the two types of firm. To fully characterize their investment we need the derivatives $\frac{\partial \underline{U}_2}{\partial \underline{\beta}_2}$ and $\frac{\partial \overline{U}_2}{\partial \overline{\beta}_2}$ at L or H, corresponding to second-period equilibria b, c and d. Differentiating the first-order conditions defining these equilibria we can show:

Second-Period Equilibrium b: $\frac{\partial \underline{U}_2(H)}{\partial \underline{\beta}_2} > -1$; $\frac{\partial \underline{U}_2(L)}{\partial \underline{\beta}_2} > -1$; $\frac{\partial \overline{U}_2(H)}{\partial \overline{\beta}_2} = \frac{\partial \overline{U}_2(L)}{\partial \overline{\beta}_2} = 0$.

Hence $\underline{i} \geq 0$, and mimicking investment $\tilde{\underline{i}} \geq 0$ (where $\underline{i} = \tilde{\underline{i}} = 0$ if $\frac{\partial \underline{U}_2}{\partial \underline{\beta}_2} \leq 0$) for the efficient firm, but $\overline{i} = \tilde{\overline{i}} = 0$ for the inefficient firm.

Second-Period Equilibrium c: $\frac{\partial \underline{U}_2}{\partial \underline{\beta}_2} = -1$; $\quad \frac{\partial \overline{U}_2}{\partial \overline{\beta}_2} = 0$.

Hence, as before, $\underline{i} \geq 0$, and mimicking investment $\tilde{\underline{i}} \geq 0$ for the efficient firm, but $\overline{i} = \tilde{\overline{i}} = 0$ for the inefficient firm.

Second-Period Equilibrium d: $\frac{\partial \underline{U}_2}{\partial \underline{\beta}_2} = \frac{\partial \overline{U}_2}{\partial \overline{\beta}_2} = -1$.

Now, as a result of the extra rent offered by a regulator of type $\alpha > \overline{\alpha}_2$, $\underline{i}$, $\overline{i}$, $\tilde{\underline{i}}$ and $\tilde{\overline{i}}$ can all be positive.

All these results follow immediately from the definitions of the various equilibria, apart from the proof that $\frac{\partial \underline{U}_2(H)}{\partial \underline{\beta}_2} > -1$ and $\frac{\partial \underline{U}_2(L)}{\partial \underline{\beta}_2} > -1$ in second-period equilibrium b, which is provided in the Appendix. As we have already discussed, in all the equilibria where investment is not zero we can have under-investment or over-investment, the latter only occurring if the first-period effort is below its Ramsey-optimum.

4.4 Bayesian Up-dating

Given that the efficient firm may mimic the inefficient firm with probability $1-x$, and the inefficient may mimic the efficient firm with probability $1-y$, the probabilities of arriving at L and H are:

$$\Pr(L) = \nu_1 x + (1-\nu_1)(1-y)\,; \quad \Pr(H) = \nu_1(1-x) + (1-\nu_1)y \tag{34}$$

Then by Bayes' Rule we have

$$\begin{aligned} \nu_2(L) &= \Pr(\text{firm is efficient} \mid \text{low cost contract has been accepted}) \\ &= \frac{\nu_1 x}{\Pr(L)} = \frac{\nu_1 x}{(\nu_1 x + (1-\nu_1)(1-y))} && (35) \\ \nu_2(H) &= \Pr(\text{firm is efficient} \mid \text{high cost contract has been accepted}) \\ &= \frac{\nu_1(1-x)}{\Pr(H)} = \frac{\nu_1(1-x)}{(\nu_1(1-x) + (1-\nu_1)y)} && (36) \end{aligned}$$

4.5 First-Period Contract

Now consider the design of contracts $(\underline{p}_1, \underline{C}_1)$ and $(\overline{p}_1, \overline{C}_1)$, given ν_1. It is convenient to formulate the regulator's problem in terms of the choice of output and effort levels and the probabilities x and y. Noting that $E[W_2] = \Pr(L)E[W_2 \mid L] + \Pr(H)E[W_2 \mid H]$, the first-period optimization problem for the regulator of type α is then:

Given ν_1, choose x, y, $(\overline{q}_1, \overline{e}_1)$ and $(\underline{q}_1, \underline{e}_1)$ to maximize

$$\begin{aligned} \Omega = E[W_1 + \delta W_2] &= \nu_1[xW(\underline{q}_1, \underline{e}_1, \underline{\beta} + i(\underline{e}_1), \alpha) + (1-x)W(\overline{q}_1, \tilde{\underline{e}}_1, \underline{\beta} + i(\tilde{\underline{e}}_1), \alpha)] \\ &+ (1-\nu_1)[yW(\overline{q}_1, \overline{e}_1, \overline{\beta} + i(\overline{e}_1), \alpha) + (1-y)W(\underline{q}_1, \tilde{\overline{e}}_1, \overline{\beta} + i(\tilde{\overline{e}}_1), \alpha)] \\ &+ \delta E[W_2] && (37) \end{aligned}$$

subject to $\underline{IC}_1$, $\overline{IC}_1$, $\underline{IR}_1$ and $\overline{IR}_1$.

Let the rent obtained when each firm mimics the other be given by

$$\tilde{\underline{U}}_1 = \overline{U}_1 + \psi(\overline{e}_1) - \psi(\tilde{\underline{e}}_1)\,; \quad \tilde{\overline{U}}_1 = \underline{U}_1 + \psi(\underline{e}_1) - \psi(\tilde{\overline{e}}_1) \tag{38}$$

where from (14) and (31) we have that

$$\tilde{\underline{e}}_1 = \overline{e}_1 - \Delta\beta + i(\tilde{\underline{e}}_1) - i(\overline{e}_1)\,; \quad \tilde{\overline{e}}_1 = \underline{e}_1 + \Delta\beta + i(\tilde{\overline{e}}_1) - i(\underline{e}_1)$$

Hence $\tilde{\underline{e}}_1 = \tilde{\underline{e}}_1(\overline{e}_1)$ and $\tilde{\overline{e}}_1 = \tilde{\overline{e}}_1(\underline{e}_1)$ and (38) can be written

$$\tilde{\underline{U}}_1 = \overline{U}_1 + \Theta(\overline{e}_1)\,; \quad \tilde{\overline{U}}_1 = \underline{U}_1 - \Gamma(\underline{e}_1)$$

Also, let $s(L)$ and $s(H)$ denote the state vectors at L and H respectively. Then the first-period incentive compatibility and individual rationality constraints are given by:

$$\begin{aligned} \underline{IC}_1 : \underline{U}_1 + \delta\underline{U}_2(s(L)) &\geq \tilde{\underline{U}}_1 + \delta\underline{U}_2(s(H)) \\ \overline{IC}_1 : \overline{U}_1 + \delta\overline{U}_2(s(H)) &\geq \tilde{\overline{U}}_1 + \delta\overline{U}_2(s(L)) \\ \underline{IR}_1 : \underline{U}_1 + \delta\underline{U}_2(s(L)) &\geq 0 \\ \overline{IR}_1 : \overline{U}_1 + \delta\overline{U}_2(s(H)) &\geq 0 \end{aligned}$$

It is clear that $\underline{IC}_1 + \overline{IR}_1 \Rightarrow \underline{IR}_1$ so that, as for the second-period contract, we can ignore the latter. Also, since either $\overline{U}_2 = 0$ in second-period equilibria b and c, or $\overline{U}_2$ is independent of H and L in equilibrium d, we must have that $\overline{U}_2(s(H)) = \overline{U}_2(s(L))$. The $\overline{IC}_1$ constraint therefore simplifies to $\overline{U}_1 \geq \tilde{\overline{U}}_1$.

As before, to solve this optimization problem, we let $\mu_1 \geq 0$, $\zeta_1 \geq 0$ and $\xi_1 \geq 0$ be the Lagrangian multipliers associated with the $\underline{IC}_1$, $\overline{IC}_1$ and $\overline{IR}_1$ constraints respectively. Then defining the Lagrangian

$$\mathcal{L}_1 = \Omega + \mu_1[\underline{U}_1 - \tilde{\underline{U}}_1 + \delta(\underline{U}_2(s(L)) - \underline{U}_2(s(H))] + \zeta_1[\overline{U}_1 - \tilde{\overline{U}}_1] + \xi_1[\overline{U}_1 + \delta\overline{U}_2(s(H))]$$

the first-order conditions are

$$\underline{L}_1 = \frac{\underline{p}_1 - c}{\underline{p}_1} = \frac{\mu_1 - \zeta_1 + (\nu_1 x + (1-\nu_1)(1-y))(\alpha - 1)}{[\mu_1 - \zeta_1 + (\nu_1 x + (1-\nu_1)(1-y))\alpha]\eta(\underline{q}_1)} \tag{39}$$

$$\overline{L}_1 = \frac{\overline{p}_1 - c}{\overline{p}_1} = \frac{\xi_1 - \mu_1 + \zeta_1 + (\nu_1(1-x) + (1-\nu_1)y)(\alpha - 1)}{[\xi_1 - \mu_1 + \zeta_1 + (\nu_1(1-x) + (1-\nu_1)y)\alpha]\eta(\overline{q}_1)} \tag{40}$$

$$
\begin{aligned}
& (\alpha\nu_1 x + \mu_1 - \zeta_1)(1 - \psi'(\underline{e}_1)) + \zeta_1 \Gamma'(\underline{e}_1) \\
- \quad & [\alpha\nu_1 x(1 - \delta f'(\underline{i})) + \mu_1(1 - \psi'(\underline{e}_1)) - \zeta_1] i'(\underline{e}_1) \\
- \quad & \alpha(1 - \nu_1)(1 - y)(1 - \delta f'(\tilde{\bar{i}})) i'(\tilde{\bar{e}}_1) \tilde{\bar{e}}_1'(\underline{e}_1) \; = \; 0
\end{aligned} \tag{41}
$$

$$
\begin{aligned}
& (\alpha(1 - \nu_1) y + \xi_1 - \mu_1 + \zeta_1)(1 - \psi'(\bar{e}_1)) - \mu_1 \Theta'(\bar{e}_1) \\
- \quad & [\alpha(1 - \nu_1) y(1 - \delta f'(\bar{i})) + \xi_1(1 - \psi'(\bar{e}_1)) - \mu_1 + \zeta_1] i'(\bar{e}_1)) \\
- \quad & [\alpha\nu_1(1 - x)(1 - \delta f'(\tilde{\underline{i}})) + \mu_1 \psi'(\tilde{\underline{e}}_1)] i'(\tilde{\underline{e}}_1) \tilde{\underline{e}}_1'(\bar{e}_1) \; = \; 0
\end{aligned} \tag{42}
$$

$$
\mu_1(\underline{U}_1 - \tilde{\underline{U}}_1 - \delta(\underline{U}_2(s(H)) - \underline{U}_2(s(L))) \; = \; 0 \tag{43}
$$

$$
\zeta_1(\overline{U}_1 - \tilde{\overline{U}}_1) \; = \; 0 \tag{44}
$$

$$
\xi_1(\overline{U}_1 + \delta \overline{U}_2(s(H))) \; = \; 0 \tag{45}
$$

In Period 1, unlike Period 2 the $\overline{IC}_1$ constraint can bind. The reason for this is the ratchet effect: the higher rent required by the efficient type to prevent it from mimicking and thus enjoying information rent in the second period is also attractive to the inefficient firm. The ratchet effect increases with the discount factor δ (and disappears as $\delta \to 0$ where the set-up in effect is static). As the weight α increases in Period 2 second-period equilibria c and d emerge offering the efficient type second-period rent even when it reveals its type in Period 1. This in turn reduces the ratchet effect and constraints $\overline{IC}_1, \underline{IC}_1$ and $\overline{IR}_1$ cease to bind in that order giving four first-period equilibria: 'equilibrium a' where all bind, 'equilibrium b' where $\underline{IC}_1$ and $\overline{IR}_1$ bind, 'equilibrium c' where only $\overline{IR}_1$ binds and 'equilibrium d' the unconstrained case. The intuition is the same as that set out after Proposition 3. Analytically we are not able to prove an analogous proposition for the first-period contracts, but numerical results, such as those displayed in Figure 3 below, indicate this may be a general result for both periods.

4.6 The Possible Equilibria

Taking the second and first-period contracts together, we now have many possible equilibria, depending on the parameters defining cost and demand conditions and the payoffs of the firm and regulator. Each configuration of parameters determines which IC and IR constraints bind in each period. Table 1 sets out the possibilities. Each row describes a particular combination of first-period constraints. The columns describe second-period constraints and depend on whether a low cost (L) or high cost (H) first-period contract has been observed.[14] The delegation decision on the type of regulator, captured by α, is particularly crucial for determining which equilibrium applies.

	$\underline{IC}_{2L}, \overline{IR}_{2L}$	$\overline{IR}_{2L}$	None	$\underline{IC}_{2H}, \overline{IR}_{2H}$	$\overline{IR}_{2H}$	None
$\underline{IC}_1, \overline{IC}_1, \overline{IR}_1$	(a, b_L)	(a, c_L)	(a, d_L)	(a, b_H)	(a, c_H)	(a, d_H)
$\underline{IC}_1, \overline{IR}_1$	(b, b_L)	(b, c_L)	(b, d_L)	(b, b_H)	(b, c_H)	(b, d_H)
$\overline{IR}_1$	(c, b_L)	(c, c_L)	(c, d_L)	(c, b_H)	(c, c_H)	(c, d_H)
None	(d, b_L)	(d, c_L)	(d, d_L)	(d, b_H)	(d, c_H)	(d, d_H)

Table 1. The Possible Equilibria.

Let us now consider each row of this table in turn:

Equilibria $(a, *)$: $\overline{IC}_1, \underline{IC}_1, \overline{IR}_1$ bind $(\zeta_1, \mu_1, \xi_1 > 0)$.

Then given x and y, $\underline{q}_1, \overline{q}_1$, $\underline{e}_1$, and $\overline{e}_1$, are given by (39), (40), (41), (42), (43) and (44), given the functions $i = i(e_1)$ and $i'(e_1)$ obtained in section 4.3. This system of equations allows the possibility of all efforts being greater or less than the Ramsey optimum. The optimal mechanism for a regulator of type α is then found by maximizing the intertemporal utility (37) with respect to x and y.

Equilibria $(b, *)$: $\underline{IC}_1, \overline{IR}_1$ bind $(\zeta_1 = 0;\ \mu_1, \xi_1 > 0)$.

The inefficient firm now does not mimic, so the solution is found by putting $y = 1$, solving (39), (40), (41), (42), (43) and (45), for $\mu_1, \xi_1 > 0$, $\underline{q}_1, \overline{q}_1$, $\underline{e}_1$, and $\overline{e}_1$, for a given x, and then maximizing (37) with respect to x. Now we have that $\underline{e}_1 = e^{RO}$.

[14] Laffont and Tirole (1993), chapter 9, derive a non-commitment PBE equilibrium for a procurement problem where contracts are transfers conditional on cost, there is no delegation ($\alpha = \alpha_s = 1$), and no investment. What they call types III and type I equilibria correspond to our equilibria (a, b) and (b, b) respectively.

Equilibria $(c,*)$: $\overline{IR}_1$ binds ($\zeta_1 = \mu_1 = 0$; $\xi_1 > 0$).

There is now no mimicking by either type of firm and it is now easy to characterize the equilibrium. Putting $x = y = 1$, information sets L and H become singletons and we have that $\nu_2(L) = 1$, $\nu_2(H) = 0$, $Pr(L) = \nu_1$ and $Pr(H) = 1 - \nu_1$. Then:

$$\underline{L}_1 = \frac{\underline{p}_1 - c}{\underline{p}_1} = \frac{\alpha - 1}{\alpha\eta(\underline{q}_1)} \tag{46}$$

$$\overline{U}(\overline{q}_1, \overline{e}_1, \overline{\beta}_1) + \delta\overline{U}_2 = 0 \tag{47}$$

$$\overline{e}_1 = \underline{e}_1 = e^{RO} \tag{48}$$

Equilibria $(d,*)$: Unconstrained. ($\zeta_1 = \mu_1 = \xi_1 = 0$)

This is the simplest case to characterise. Equations (46) and (48) apply as before and (47) now becomes

$$\overline{L}_1 = \frac{\overline{p}_1 - c}{\overline{p}_1} = \frac{\alpha - 1}{\alpha\eta(\overline{q}_1)} \tag{49}$$

In fact we can rule out some of these possible equilibria. The ratchet effect means that first-period constraints $\overline{IC}_1$ and $\underline{IC}_1$ must bind before their second-period counterparts. Similarly $\overline{IR}_1$ must bind before $\overline{IR}_2$; otherwise the contracts offer rent to the inefficient type in the first period, but not the second. Yet the only reasons for offering the inefficient type rent would be a pro-industry regulator who sufficiently likes rent, in which case she would offer it in both periods (equilibrium (d,d)), or a regulator who wishes to encourage investment, in which case rent is offered in the second-period only. These considerations imply that as α increases above unity, second-period constraints cease before their first-period counterparts, **ruling out lower-diagonal equilibria** $(c, b_L), (d, b_L)$, (d, c_L) and $(c, b_H), (d, b_H)$, (d, c_H).

The implications for investment of these results now follow from section 4.3. They are summarised in our final proposition:

Proposition 5. *The equilibria exhibit the following investment behaviour:*
(i) Over- or under-investment or Ramsey-optimal investment by the efficient firm; no investment by the inefficient firm (equilibria (a,b), (a,c), (b,b) and (b,c)).
(ii) Ramsey-optimal investment by the efficient firm; no investment by the inefficient firm (equilibrium (c,c)).

(iii) Over- or under-investment or Ramsey-optimal investment by both (equilibria (a,d) and (b,d)).
(iv) Ramsey-optimal investment by both (equilibria (c,d) and (d,d)).

4.7 Numerical Results

Our five propositions describe the main properties of price regulation with and without commitment, and, for the latter, of delegation to a pro-industry regulator. We now turn to numerical solutions to illustrate these properties and to provide insights into the welfare analysis that follows. We first choose functional forms for managerial disutility, the inverse demand function and the investment function: $\psi(e) = \frac{\gamma}{2}(\max(0,e))^2$, $q = \phi(p) = Ap^{-\eta}$, $\eta > 1$ and $f(i) = Bi^{\theta}$; $\theta \in (0,1)$. Our baseline selection of parameters is: $\underline{\beta} = 2$, $\overline{\beta} = 2.5$, $c = \gamma = B = 1$, $A = 10$, $\eta = 1.5$, $\nu_1 = \theta = 0.5$, $\delta = 0.6$ and $\alpha = \alpha_s = 1$ (no delegation).[15] With these choices we have $e^{RO} = 1/\gamma = 1$ and $i^{RO} = (\delta\theta B)^{\frac{1}{1-\theta}}$. We present variations $\alpha \in [1, 1.8]$ and, in section 5, $B \in \{0, 1.5\}$. It turns out that for these choices $(a, *)$ type equilibria do not occur. For the $(b, *)$ type equilibria, which do occur, the optimal incentive mechanism is found by maximizing the social welfare function over $x \in [0, 1]$, where, we recall, x is the probability that the efficient firm mimics the inefficient firm in period 1. However here we avoid the complications arising from x changing with every parameter combination and present results for an exogenously chosen $x = 0.5$.[16]

Figure 3 plots selected variables against α. In Figure 3a, first-period Lerner indices for the efficient and inefficient firms show the values of α for which the equilibria $(b, *)$, $(c, *)$, and $(d, *)$ apply. For $\alpha \in [1, 1.45]$, equilibria are of type $(b, *)$. Then, as predicted by our analysis, as α increases, first the constraint $\overline{IC}_1$ ceases to bind giving equilibria types $(c, *)$ and then, at $\alpha = 1.475$, the $\overline{IR}_1$ also ceases to bind leaving the equilibria of type $(d, *)$.

Figure 3b shows the corresponding investment behaviour by the efficient firm (non-

[15] $\delta = 0.6 \approx 0.9^5$ can be rationalized as a 10% per year discount rate with a 5-year regulatory review period.
[16] Therefore we actually underestimate the welfare gains from delegation reported in section 5. All numerical results are obtained using programs written in MATLAB. These are available to the reader on request.

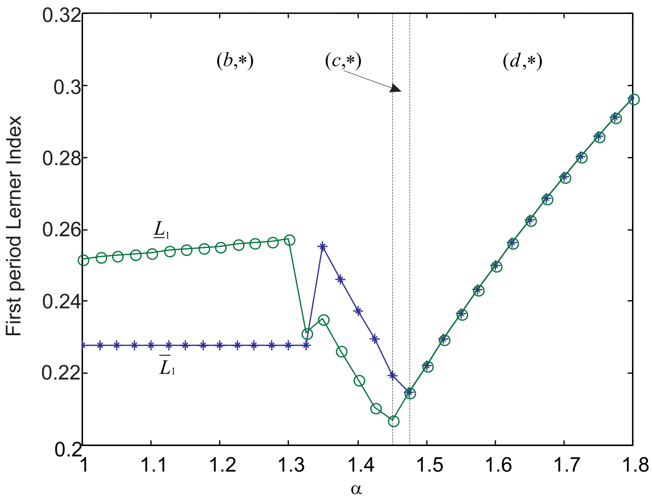

Figure 3a: First period Lerner Indices

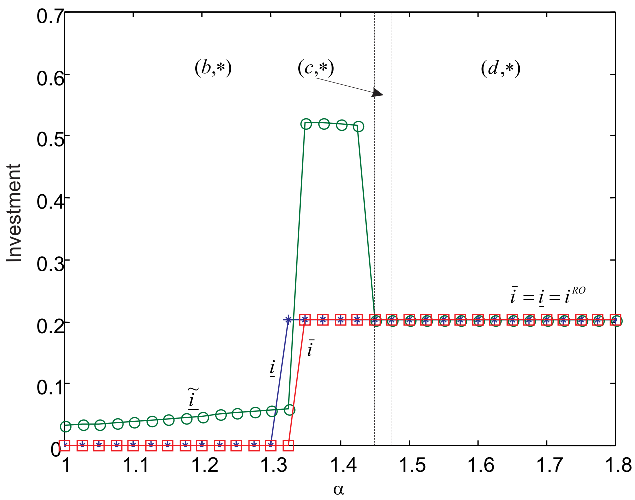

Figure 3b: Investment

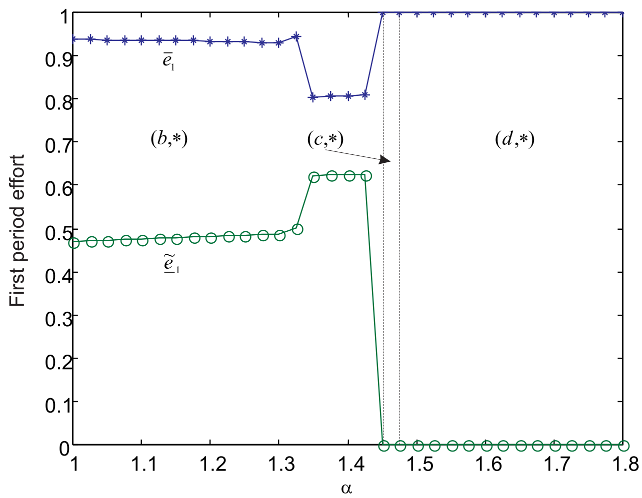

Figure 3c: First period effort

mimicking investment $\underline{i}$ and mimicking investment $\tilde{\underline{i}}$) and by the inefficient firm $\bar{i}$. All results are consistent with the predictions of Proposition 5. In the $(b,*)$ equilibria, the efficient firm over-invests for sufficiently high α when mimicking. Non-mimicking investment starts at zero since at L the efficient firm reveals its type and rent is zero in a (b,b) equilibrium. Then in (b,c) and (b,d) equilibria, since $\underline{e}_1 = 1$, investment rises to its Ramsey optimum. For higher α, in equilibria $(c,*)$, for which (c,c_L), (c,d_L), and (c,c_H), (c,d_H) can occur at L and H respectively, (c,d_H) turns out to be the equilibrium type at H, and both types of firm invest at the Ramsey-optimum. As α increases further, in equilibria (d,d_L) and (d,d_H) this investment behaviour continues.

Figure 3c plots mimicking first-period effort by the efficient firm, $\tilde{\underline{e}}_1$ and the first-period effort of the inefficient firm, $\bar{e}_1$. Recalling that $e^{RO} = 1$ for our choice of managerial utility function and parameters, the figure shows that $\bar{e}_1 < 1$ and $\tilde{\underline{e}}_1 < 1$ in the $(b,*)$ equilibria. From the investment decision (see (31)) we have that $\psi'(\tilde{\underline{e}}_1) = \gamma\tilde{\underline{e}}_1 = \delta f'(\tilde{\underline{i}})$. This explains why $\tilde{\underline{i}} > i^{RO}$ and over-investment occurs in Figure 3b.

Figure 3d shows the rent of the efficient firm in the first period and at L and H in the second period. The most interesting feature of this figure is the drop in the first-period rent $\underline{U}_1$ and the corresponding rise in the second-period rent $\underline{U}_{2L}$ at L. This illustrates the reduction in the ratchet effect brought about by delegation to a

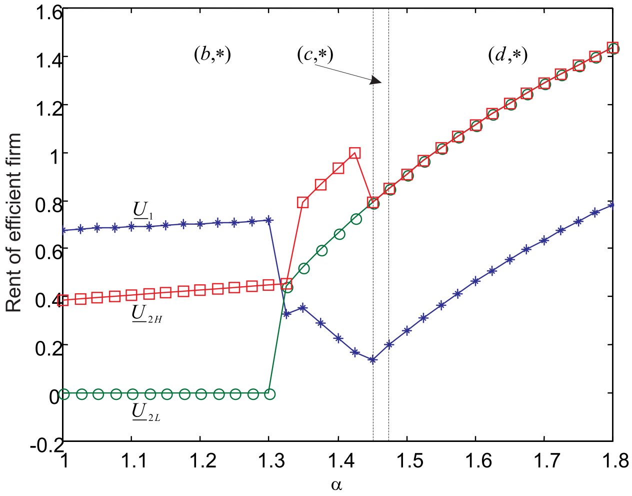

Figure 3d: Rent of efficient firm

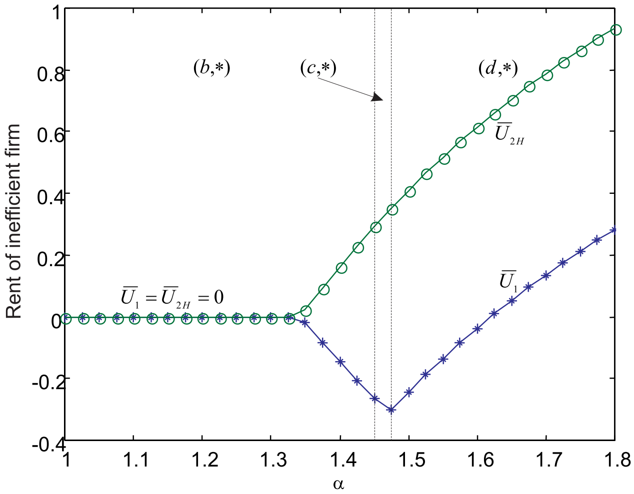

Figure 3e: Rent of inefficient firm

pro-industry regulator. To see this effect clearly, rewrite the $\underline{U}_1$ constraint (39) in binding form as

$$\underline{U}_1 = \underline{\tilde{U}}_1 + \delta(\underline{U}_{2H} - \underline{U}_{2L})$$

where mimicking rent is $\tilde{\underline{\tilde{U}}}_1 = \overline{U}_1 + \Theta(\overline{e}_1)$. Thus the promise of second-period rent at L results in a lower incentive-compatible rent in the first period. Figure 3e shows the corresponding rent for the inefficient firm. In equilibria (b, b_H), (b, c_H) and (c, c_H), $\overline{U}_{2H} = \overline{U}_1 = 0$, but in (b, d_H) we have that $\overline{U}_{2H} > 0$. However the two-period discounted rent is still zero, so $\overline{U}_1$ falls in this region. In the region for which (d, d_H) applies, the two-period discounted rent starts to rise with α.

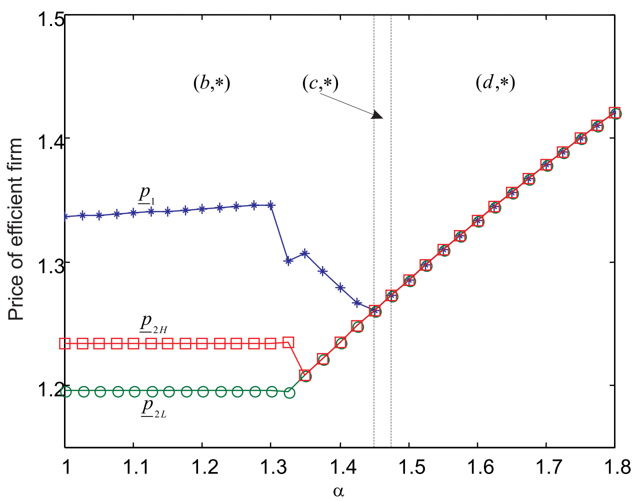

Figure 3f: Price of efficient firm

Finally Figures 3f and 3g give the regulated prices offered to the efficient and inefficient firms respectively. The sharp fall in the regulated price for the efficient type corresponds to the fall in the ratchet effect discussed above, and yields the main benefit to the consumer. The consumer also benefits from a drop in the inefficient firm's prices in both periods as α increases. These benefits are maximized at a value $\alpha = 1.45$. The efficient firm's discounted rent rises with delegation, whereas that of the inefficient firm is constant at zero. Thus we conclude that *delegation can be Pareto-improving*; both consumers and the firm can benefit if α is carefully chosen.

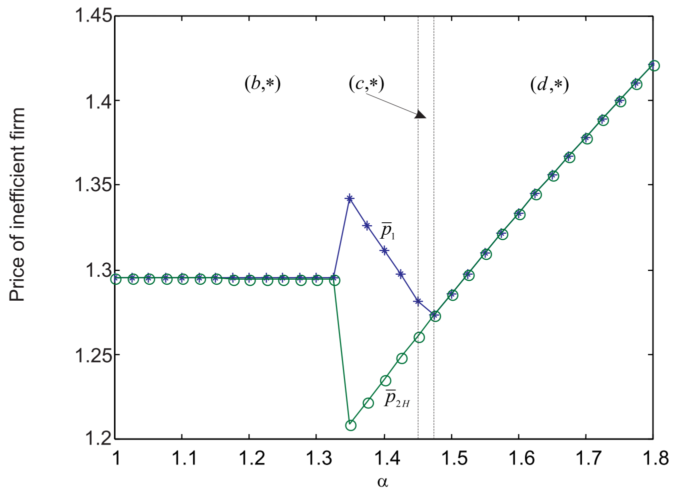

Figure 3g: Price of inefficient firm

5 Welfare Analysis

We have seen that delegation to a pro-industry regulator with a carefully chosen preference parameter α can increase investment, reduce the ratchet effect and result in both lower prices, benefiting consumers, and higher rent. This section investigates these welfare gains further, compares them with the welfare gain from full commitment and examines the scope for a wrong choice of α that leads to counterproductive delegation. First consider the single-period social welfare (3):

$$W_t = S(p_t) - R(p_t) + \alpha_s U_t = W(p_t, U_t, \alpha_s)$$

Then having obtained prices and rents in a PBE with a regulator of type α, we can write the two-period social welfare as

$$\begin{aligned} \Omega(\alpha, \alpha_s) &= \nu_1[xW(\underline{p}_1(\alpha), \underline{U}_1(\alpha), \alpha_s) + (1-x)W(\overline{p}_1(\alpha), \underline{\tilde{U}}_1(\alpha), \alpha_s)] \\ + &\quad (1-\nu_1)[yW(\overline{p}_1(\alpha), \overline{U}_1(\alpha), \alpha_s) + (1-y)W(\underline{p}_1(\alpha), \tilde{\overline{U}}_1(\alpha), \alpha_s)] + E[W_2(\alpha, \alpha_s)] \end{aligned}$$

where

$$\begin{aligned} E[W_2(\alpha,\alpha_s)] &= (\nu_1 x + (1-\nu_1)(1-y))E[W_2|L] + (\nu_1(1-x) + (1-\nu_1)y)E[W_2|H] \\ E[W_2|L] &= \nu_{2L} W(\underline{p}_{2L}(\alpha), \underline{U}_{2L}(\alpha), \alpha_s) + (1-\nu_{2L})W(\overline{p}_{2L}(\alpha), \overline{U}_{2L}(\alpha), \alpha_s) \\ E[W_2|H] &= \nu_{2H} W(\underline{p}_{2H}(\alpha), \underline{U}_{2H}(\alpha), \alpha_s) + (1-\nu_{2H})W(\overline{p}_{2H}(\alpha), \overline{U}_{2H}(\alpha), \alpha_s) \end{aligned}$$

We measure the welfare gain from delegation, $G(\alpha)$ as follows. Let Ω^C be the optimal two-period social welfare under commitment. Then

$$G(\alpha) = \frac{(\Omega(\alpha,\alpha_s) - \Omega(\alpha_s,\alpha_s))}{(\Omega^C - \Omega(\alpha_s,\alpha_s))} \times 100$$

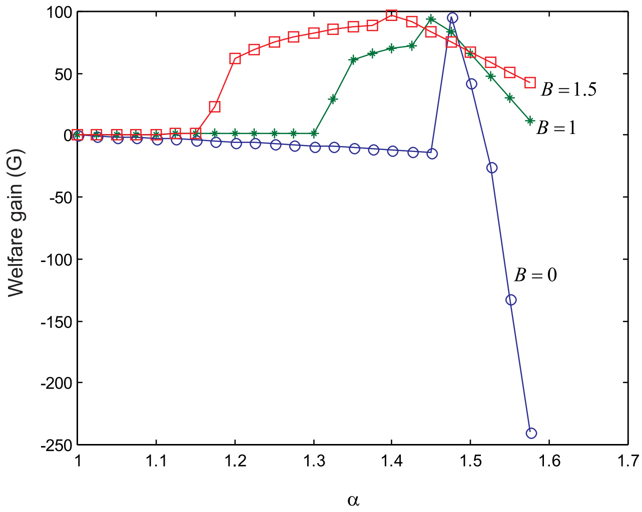

Figure 4: Welfare gains from delegation

Thus $G(\alpha) \leq 100\%$ and measures the extent to which delegation can substitute for full commitment. Figure 4 plots $G(\alpha)$ against α for $B = \{0, 1, 1.5\}$. The case of $B = 0$ shows the ability of delegation to mitigate the ratchet effect on its own, without investment considerations. These results demonstrate the possibility of significant welfare gains from delegation with the appropriate choice of α. However without investment considerations a regulator who is only slightly too pro-industry leads to a welfare loss. Delegation is far more robust (and the range of 'beneficial' regulators is considerably wider) if investment is introduced, especially if its impact on costs is at the higher level of $B = 1.5$.

6 Conclusions and Future Research

The question of how to encourage investment by regulated industries is a central one for regulators. Problems arise because despite the benefits of investment (lower costs), regulators ex post have an incentive to lower prices, which firms anticipate. A number of authors have identified the resulting 'under-investment' in a variety of regulatory settings. The present paper considers a dynamic non-commitment problem and makes several contributions to the analysis of the under-investment problem. First, we show how strategic delegation to a suitable type of regulator can overcome the under-investment problem (as well as the ratchet effect that also arises in the model). Second, we focus on non-contractible investment in the presence of asymmetric information about other cost-reducing effort by the firm. Third, the regulator is not permitted to use transfers in order to reimburse the firm. The full set of Perfect Bayesian Equilibria is characterised. We suggest that each of these contributions accords with features of the regulatory environment, for example in the UK.

Our results throw some light on how a regulatory regime might achieve effective regulation. This must achieve: (i) the freedom to respond to the latest information regarding the industry; i.e., it must involve discretion; (ii) socially optimal investment and effort, ruling out direct controls or 'rate-of-return' regulation and (iii) consumer benefits from higher investment through lower prices. Our paper shows that, with discretion, delegation of price regulation to an independent regulator of the appropriate type will achieve these objectives.

This in a sense is a positive rather than normative result. If we observe good regulation it could be coming about through this mechanism. To derive normative conclusions we note that, in common with much of the strategic delegation literature, we have relocated the problem as one of choosing the correct α, but we have not addressed directly how an appropriate regulator can be found. While it is reasonable to suppose that track records can play a valuable role here, it may still be sensible to consider safeguards against 'mistakes'. In this respect, Spulber and Besanko (1992)'s suggestion that legal rules can be helpful for implementing simple (but clear) policy objectives is relevant. Thus, one could imagine statutory limits on the maximum prices that regulators could set, so as to curtail excessively pro-industry behaviour. Furthermore new regulators without a clear track-record should be aware of the problem posed in our model and be prepared to build up a reputation for achieving the 'right balance between the needs of consumers and the firm' (i.e., a reputation for having the right α). Formal modelling of this process would be worthwhile in future work.

Our analysis makes predictions about the effects of regulatory independence on investment, costs and prices (see also Currie *et al.* (1999)). An important requirement for testing these predictions would be a suitable index of regulatory independence in various countries/industries in order to compare different regulatory regimes. Naturally, such an index would be complex to produce. However, to the extent that regulatory independence can be shown to have benefits in theory, such empirical work would provide important insights for policy makers in this area.

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A Proofs

Proposition 1

(i) The assumption that fixed costs must be positive implies that the Lerner indices (8) and (9) must be positive. Hence for $\alpha = \alpha_s \leq 1$ we have that $\mu > \zeta$ and $\xi - \mu + \zeta > 0$. Therefore since $\zeta \geq 0$ it follows that $\mu > 0$ and $\xi > \mu - \zeta > 0$ and therefore $\underline{IC}$ and $\overline{IR}$

bind. To show that $\overline{IC}$ does not bind, we prove by method of contradiction. Suppose that $\overline{IC}$ binds along with $\underline{IC}$ and $\overline{IR}$. Then from (12), we have that

$$\sum_{t=1}^{2} \delta^{t-1}\Phi(\overline{e}_t) = \sum_{t=1}^{2} \delta^{t-1}\Phi(\overline{e}_t + \Delta\beta_t) = 0 \tag{A.1}$$

¿From (iii), proved below, both types invest at the RO (and this is true even if $\zeta > 0$). It follows that $\Delta\beta_2 > 0$; $t = 1, 2$. But now (A.1) contradicts the property $\Phi' > 0$. Hence the assumption that $\overline{IC}$ binds is false.

(ii) $\underline{e}^C = e^{RO}$ and $\overline{e}^C < e^{RO}$ follow from (10) with $\zeta = 0$ and from (11) with $\mu > 0$.

(iii) $\underline{i}^C = \overline{i}^C = i^{RO}$ follows from (31) since, as noted above, $\mu > \zeta$ and $\xi > \mu - \zeta$.

(iv) From (8) and (9) $\eta(\overline{q}_t)L(\overline{q}_t) > \eta(\underline{q}_t)L(\underline{q}_t)$ iff $\xi - \mu + (1 - nu_1)(\alpha - 1))(\mu + \nu_1\alpha) > \xi - \mu + (1 - nu_1)\alpha)(\mu + \nu_1)(\alpha - 1)$, which after some algebraic manipulation reduces to $\xi > \mu$ which we have shown to be true. If $\eta(q_t)$ is non-increasing (and in particular if it is constant) then it follows that $\overline{L}_t > \underline{L}_t$. Hence $\overline{p}^C > \underline{p}^C$ and $\overline{q}^C < \underline{q}^C$.

(v) For both types of firm we have $U_1 = (p_1 - c)q_1 - (\beta - e_1 + i) - \psi(e_1)$, $U_2 = (p_2 - c)q_2 - (\beta - e_2 - f(i)) - \psi(e_2)$, $p_1 = p_2$, $q_1 = q_2$ and $e_1 = e_2$. Hence $U_2 = U_1 + i + f(i)$. $U_2 > U_1$ therefore follows. From the $\overline{IR}$ constraint it therefore follows that $\overline{U}_1^C < 0$ and $\overline{U}_2^C > 0$; but $\underline{U}_1^C > 0$ and $\underline{U}_2^C > 0$ is possible for the efficient type.

Propositions 2: The proof is essentially the same as Proposition 1.

Proposition 3: To prove this proposition we first require two lemmas:

Lemma 1 $\frac{d(R(q)-cq)}{dq} < 0$ where $R(q) = pq$ is revenue.

Proof. $(R(q) - cq)dq = p(1 - \frac{1}{\eta(q)}) < 0$ follows from $\frac{p-c}{p} < \frac{1}{\eta(q)}$, the monopoly mark-up.

Lemma 2: Assume that $e^{RO} > \Delta\beta$. Then the information rent function $\Phi(e^{RO}) = \psi(e^{RO}) - \psi(e^{RO} - \Delta\beta) < \Delta\beta$.

Proof. By the Mean Value Theorem: $\psi(e^{RO}) - \psi(e^{RO} - \Delta\beta) < \psi'(x)\Delta\beta$ for some $x \in [e^{RO} - \Delta\beta, e^{RO}]$. But since $\psi'' > 0$, $\psi'(x) < \psi'(e^{RO}) = 1$ proving the Lemma.

(i) Suppose $\overline{IR}_2$ and $\underline{IC}_2$ bind. Then

$$\begin{aligned} R(\overline{q}_2) - c\overline{q}_2 &= \overline{\beta}_2 - \overline{e}_2 + \psi(\overline{e}_2) \\ R(\underline{q}_2) - c\underline{q}_2 &= \Phi(\overline{e}_2)\underline{\beta}_2 - \underline{e}_2 + \psi(\underline{e}_2) \end{aligned}$$

Therefore from Lemma 1 $\underline{q}_2 > \overline{q}_2$ iff $\Phi(\overline{e}_2 < \Delta\beta_2 + \overline{e}_2 - \psi(\overline{e}_2) - (\underline{e}_2 - \psi(\underline{e}_2)$. This condition holds because from Lemma 2, $\Phi(\overline{e}_2) < \Delta\beta_2$, $\underline{e}_2 = e^{RO}$ and $e - \psi(e)$ reaches a maximum at $e = e^{RO}$.

(ii) Follows from differentiating (19) to (20).

(iii)With $\zeta_2 = 0$, write (16) and (17) as

$$\begin{aligned} \mu_2 &= \nu_2 \left[\frac{1}{1 - \eta(\underline{q}_2)\underline{L}_2} - \alpha \right] \\ \xi_2 - \mu_2 &= (1 - \nu_2) \left[\frac{1}{1 - \eta(\overline{q}_2)\overline{L}_2} - \alpha \right] \end{aligned}$$

Therefore as α increases, $\mu_2 = 0$ before $\xi_2 - \mu_2$ if $\underline{L}_2 < \overline{L}_2$, which is the case from (i), and $\eta(q)$ is non-increasing in q.

Proof of $\frac{\partial \underline{U}_2(H)}{\partial \underline{\beta}_2} > -1$ and $\frac{\partial \underline{U}_2(L)}{\partial \underline{\beta}_2} > -1$ in Second-Period Equilibrium b.

First note that the second-period information rent $\Phi = \psi(\overline{e}_2) - \psi(\tilde{\underline{e}}_2)$ is a function of $\overline{e}_2$ and $\Delta\beta_2$, the latter depending on investment in the first period. Write $\Phi = \Phi(\overline{e}_2, \Delta\beta_2)$. Then differentiating (19)-(20) we have that

$$\frac{\partial \underline{U}_2}{\partial \underline{\beta}_2} = \frac{\partial \Phi}{\partial \overline{e}_2} \frac{\partial \overline{e}_2}{\partial \underline{\beta}_2} - \psi'(\tilde{\underline{e}}_2) = -\frac{\partial \Phi}{\partial \overline{e}_2} \frac{a_2}{a_0 + a_1} - \psi'(\tilde{\underline{e}}_2) \tag{A.2}$$

Therefore the result holds iff $\frac{a_2}{(a_0 + a_1)} \frac{\partial \Phi}{\partial \overline{e}_2} < (1 - \psi'(\tilde{\underline{e}}_2))$ where we have defined

$$\begin{aligned} a_0 &= \frac{(1 - \nu_2)}{(1 - \eta\overline{L}_2)} \left[\frac{\eta \overline{L}_2{}'(1 - \psi'(\overline{e}_2))^2}{(1 - \eta\overline{L}_2)(\overline{p}_2(1 - \frac{1}{\eta}) - c)} + \psi''(\overline{e}_2) \right] \\ a_1 &= \nu_2 \left[\mu_2(\psi''(\overline{e}_2) - \psi''(\tilde{\overline{e}}_2) + \frac{\eta \underline{L}_2{}' \left(\frac{\partial \Phi}{\partial \overline{e}_2}\right)^2}{(1 - \eta\underline{L}_2)^2(\underline{p}_2(1 - \frac{1}{\eta}) - c)} \right] \\ a_2 &= \nu_2 \left[-\mu_2 \psi''(\tilde{\overline{e}}_2 + \frac{\eta \underline{L}_2{}' \frac{\partial \Phi}{\partial \overline{e}_2}(1 - \psi'(\tilde{\underline{e}}_2))}{(1 - \eta\underline{L}_2)^2(\underline{p}_2(1 - \frac{1}{\eta}) - c)} \right] \end{aligned}$$

From the definitions of a_2 and a_1 and the fact that $a_0 > 0$ we have that $\frac{a_2}{(a_0 + a_1)} \frac{\partial \Phi}{\partial \overline{e}_2} < \frac{a_1}{a_0 + a_1}(1 - \psi'(\tilde{\underline{e}}_2)) < (1 - \psi'(\tilde{\underline{e}}_2))$, which proves the result.