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Utility price regulation and time inconsistency: comparisons with monetary policy

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We examine the hold-up problem of price regulation and compare it with the monetary policy credibility problem. For both, reputational solutions are possible provided that the policymaker is sufficiently far-sighted, but the hold-up problem in regulation turns out to be more serious than the inflation bias problem in monetary policy. Even with far-sighted regulators, a reputational equilibrium with optimal investment is undermined if capital depreciates slowly and consumer demand increases slowly. These results make the Rogoff-delegation solution to the regulatory commitment problem especially attractive. The paper concludes with a short discussion linking these results to the empirical literature on utility regulatory regimes.

JEL classification: C72, E61, L51.

1. Introduction

Over the last 10–20 years, there has been an enormous increase in the number of countries (a) delegating monetary policy to independent central banks and (b) establishing separate regulatory agencies for utility service industries—typically with telecommunications as the pathfinder.[1] This joint development has taken place not just in the EU and other European and OECD countries, but also in many middle income countries (particularly in Latin America) and increasingly in other developing countries, including some low income countries in Asia and Africa.

The growth of these institutions has given rise to a sizeable number of academic and informal discussion both of the central bank independence (its key characteristics, governance issues, and its impact) and of regulatory agencies (their key

[1] See International Telecommunications Union (2002).

features including independence and governance). However, to date, there has been little discussion of the common relationship between the two developments. This is somewhat surprising since the prime motive force behind the two developments is very similar. Indeed, one of the main purposes of this paper is precisely to demonstrate the similarities in the underlying economic problem in each case and to show the common relationship between the adopted responses.[2] In particular we show that in both cases reputational solutions to the time inconsistency problem are available provided that the policymaker is sufficiently far-sighted. But even if regulators are far-sighted, a solution to the regulatory investment problem is undermined if capital depreciates slowly or consumer demand grows slowly. The hold-up problem in regulation turns out to be more serious than the inflation bias problem in monetary policy in that the reputational equilibrium is far more difficult to sustain. This makes more attractive the solution to strategically delegate to independent regulatory agencies who have a duty to give more weight to the firm's profit than it would be the case with a representative regulator.

For independent central banks, there has been a lot of empirical work which suggests that independent central banks—and particularly independent central banks with good governance arrangements (and practices)—are associated with better macro-economic outcomes, for example on inflation and exchange rate volatilty. As yet, there has been rather less research that has formally tested the impact of independent utility regulation and governance arrangements on utility service outcomes. This is, at least in part, because of the difficulties in specifying common desirability in outcomes (for example, on utility service price movements) across a large number of countries. Nevertheless, the empirical literature on the effects of various independent central bank governance arrangements on macroeconomic outcomes provides a strong starting point for evaluating the impact of telecoms and other utility service regulators.

It is useful to distinguish between three types of problems facing central banks, regulators and other public authorities: (i) the credibility of commitment; (ii) asymmetric information in relation to the private sector; (iii) departures from social welfare maximization arising, for example, from electoral pressures or capture by special interest groups. In this paper we focus on the first and third of these problems and we assume that the policymaker in question shares information with the private sector (and vice-versa). Although we do not formalize games with asymmetric information[3] and political economy considerations,[4] we conjecture that introducing them would reinforce our argument in favour of a form of delegation that we call 'as if' Rogoff delegation.

The plan of the rest of the paper is as follows. Section 2 presents and compares the time-inconsistency problems in the areas of price regulation and monetary

[2] An informal discussion of the policy issues is to be found in Stern and Trillas (2001).

[3] In relation to asymmetric information, Geraats (2002) provides a comprehensive review of the theoretical literature on the benefits or otherwise of central bank transparency.

[4] But see al-Nowaihi and Levine (1998), for a recent treatment of political monetary cycles.

policy. We show that there exists a close parallel between a 'high price bias' arising from the under-investment problem in utility regulation and an 'inflation bias' in the conduct of monetary policy. Section 3 sets out two possible solutions to these problems: reputational equilibria and Rogoff-delegation to 'conservative' agencies. Section 4 discusses the practical problems of implementing these solutions. Section 5 discusses the empirical literature on regulatory agencies and its relationship to that on central banks. Section 6 concludes the paper.

2. Time-inconsistency problems in price regulation and monetary policy

2.1 The hold-up problem

For utility services like telecoms there is a classic time inconsistency problem: these services require large volumes of investment which, once installed become 'sunk assets' in the sense that most or all of them cannot be removed and used elsewhere or sold on second-hand markets at their original cost. In consequence, private investors are at risk of opportunistic behaviour by governments, particularly over prices, once the investments have been installed; and awareness by private investors of this regulatory risk drives up the required rate of return and the cost of capital. The latter dramatically reduces investment as has been seen in many countries (see Levy and Spiller,1996).

In order to examine this under-investment or 'hold-up' problem, we set out below a simple model of the regulatory pricing problem for private sector utility services.[5] Our main point can be made by confining ourselves to a deterministic model with perfect foresight. A utility firm provides a final service for n_t customers at time t using a network that requires inputs of capital K_t and effective units of labour L_t according to a Cobb-Douglas constant returns to scale production function

$$n_t = K_t^{\gamma} L_t^{1-\gamma} \tag{1}$$

Customers grow at constant exogenous rate g_n so that

$$n_{t+1} = \left(1 + g_n\right) n_t \tag{2}$$

and the firm is required to provide a service to all customers. At time t, the final service is sold to each customer at a regulated price p_t and $q_t = D(p_t)$ is the demand curve per customer. This service is produced at constant marginal cost c.

[5] The basic model is close to that in Salant and Woroch (1992), but our treatment of the regulation game is as a reputational problem, rather than the trigger-strategy game of those authors. We discuss these differences further in Section 3.3.

Consider at time t a firm making investments $\{i_\tau, \tau = t, t+1, t+2, \ldots\}$ over an infinite time horizon. Its capital stock K_τ evolves according to

$$K_{\tau+1} = (1-\delta)K_\tau + i_\tau\,;\, \tau = t, t+1, t+2, \ldots \tag{3}$$

where δ is the depreciation rate. Choose the price of one unit of capital as the numeraire. Then given K_τ and L_τ, substituting $q_\tau = D(p_\tau)$ and $n_\tau = K_\tau^\gamma L_\tau^{1-\gamma}$ from (1), the firm's profit in period τ is given by

$$U_\tau = n_\tau(p_\tau - c)q_\tau - wL_\tau - i_\tau \equiv U(p_\tau, K_\tau, L_\tau, i_\tau) \tag{4}$$

where L_τ here is the labour (in effective units) employed on the infrastructure network. Now suppose that the firm plans investment and employment on infrastructure at $t = 0$ at which time K_0 and the regulated price p_0 are given. Then given expectations[6] of regulated prices $E_0\{p_\tau\}$, $\tau \geqslant 1$ and (K_0, p_0), the firm chooses investment and employment to maximize

$$E_0\left[\sum_{\tau=0}^{\infty} \beta_f^\tau U(p_\tau, K_\tau, L_\tau, i_\tau)\right] \tag{5}$$

where $\beta_f \in (0, 1)$ is the discount factor of the firm, subject to (3), (1), and a participation constraint

$$E_0\left[\sum_{\tau=0}^{\infty} \beta_f^\tau U(p_\tau, K_\tau, L_\tau, i_\tau)\right] \geqslant 0 \tag{6}$$

According to (6) the firm will carry out the investment and employment plan $\{i_\tau, L_\tau\}$ rather than close and sell and earn zero profit.[7]

Given $\{n_\tau\}$ and expected regulated prices, the firm's problem at time $t = 0$ is to minimize expected discounted costs

$$E_0\left[\sum_{\tau=0}^{\infty} \beta_f^\tau [wL_\tau + i_\tau]\right] \tag{7}$$

[6] Since our model is deterministic expected prices equal actual prices in a perfect foresight rational expectations equilibrium. We retain the expectations operator to emphasize the forward-looking nature of the investment decision and the changing nature of the participation constraint.

[7] In order to keep the model as simple as possible we ignore the scrap value of capital on closure. In an earlier version of the paper, Levine *et al.* (2004), we included this feature, but came to the same substantive conclusions.

with respect to $\{i_\tau, L_\tau\}$, $\tau \geqslant 1$ given (3), (1) and (6). The solution to this optimization problem is standard (see Appendix 1): provided that the expected regulated prices are such that the participation constraint (6) is satisfied, in the absence of any adjustment costs, the firm invests immediately to achieve its optimal capital-labour ratio given by

$$\frac{K_\tau}{L_\tau} = \frac{\gamma w}{(1-\gamma)\left(r_f + \delta\right)} \tag{8}$$

where the firm's discount rate r_f is defined by $\beta_f = 1/(1 + r_f)$. Thereafter for $\tau \geqslant 1$, capital stock and effective labour employed in infrastructure grow at the same rate g_n, the growth rate of customers.[8] Along this growth path, from (3) and the fact that the capital-labour ratio is fixed, we have that the growth in capital stock is equal to $g_n = -\delta + (i_\tau/K_\tau)$ so that investment is given by

$$i_\tau = \left(\delta + g_n\right)K_\tau \tag{9}$$

From (1) and (8) we can obtain the optimal path for capital stock as

$$K_\tau = K_\tau^* = \left[\frac{\gamma w}{(1-\gamma)\left(r_f + \delta\right)}\right]^{1-\gamma} n_\tau \tag{10}$$

Along this path the cost of providing a network for n_τ customers is minimized at $wL_\tau^* + i_\tau^* = C^*(w, r_f + \delta)n_\tau$ say where infrastructure employment L_τ^* is found from (8) and (10). Having obtained K_τ^*, L_τ^* and i_τ^* (the latter from (9)), profits along the optimal investment path are given by

$$U_\tau^* = U\left(p_\tau, K_\tau^*, L_\tau^*, i_\tau^*\right) = n_\tau\left[(p_\tau - c)q_\tau - C^*\left(w, r_f + w\right)\right] \tag{11}$$

which, as with capital stock, grows at the same rate as the number of customers.[9]

The set-up is completed by specifying the price-setting authority's intertemporal objective function at time t as

$$\Omega_t = \sum_{\tau=t}^{\infty} \beta^{\tau-t}\left[S(p_\tau) + \alpha U_\tau\right] \tag{12}$$

[8] Because effective labour increases with technical change, growth in customers can be sustained by a combination of growth in raw employment in infrastructure and this labour-augmenting technical change.

[9] A fixed entry cost, that will explain the existence of a monopoly, can be added to the cost structure without altering any of the results.

where β is the regulator's discount factor and $S(p_\tau)$ is the net consumer surplus given by

$$S(p_\tau) = n_\tau \int_{p_\tau}^{\infty} D(p')\, dp' \tag{13}$$

In (12), α is the weight the policymaker places on profits relative to consumer interests. For a utilitarian policymaker, $\alpha = 1$ and we, in general, assume that $0 \leqslant \alpha \leqslant 1$. Later, however, we consider the possibility of delegating to a 'pro-industry' regulator with $\alpha > 1$.

We can now formulate the commitment price rule that will induce the firm to invest $\{K_\tau\} = \{K_\tau^*\}$. First use (11) to rewrite the participation constraint (6) at $t = 0$ with optimal investment as

$$n_0(p_0 - c)q_0 - wL_0 - i_0 + E_0\left[\sum_{\tau=1}^{\infty} \beta_f^\tau n_\tau\left[(p_\tau - c)q_\tau - C^*\left(w, r_f + \delta\right)\right]\right] \geqslant 0 \tag{14}$$

First we assume that in period $t = 0$ the regulated price is such that $(p_0 - c)D(p_0) = wL_0$.[10] Then (14) becomes

$$E_0\left[\sum_{\tau=1}^{\infty} \beta_f^\tau n_\tau\left[(p_\tau - c)q_\tau - C^*\left(w, r_f + \delta\right)\right]\right] \geqslant i_0 \tag{15}$$

This is the *ex ante* participation constraint at $t = 0$. With the weight on rent $0 \leqslant \alpha \leqslant 1$, single period welfare $S(p_\tau) + \alpha U_\tau$ increases as the price falls towards the marginal cost and therefore the firm's participation constraint must bind. From (15), assuming that $r_f > g_n$,[11] using $\sum_{\tau=1}^{\infty} \beta_f^\tau n_\tau = \sum_{\tau=1}^{\infty} (\beta_f(1 + g_n))^\tau n_0 = \beta_f(1 + g_n)/(1 - \beta_f(1 + g_n)) = (1 + g_n)/(r_f - g_n)$, a steady state commitment price, p^C say, must satisfy

$$\left(1 + g_n\right)n_0\left[\left(p^C - c\right)D\left(p^C\right) - C^*\left(w, r_f + \delta\right)\right] = \left(r_f - g_n\right)i_0 \tag{16}$$

At $t = 1$ the *ex post* participation constraint becomes

$$E_1\left[\sum_{\tau=1}^{\infty} \beta_f^{\tau-1} n_\tau\left[(p_\tau - c)q_\tau - C^*\left(w, r_f + \delta\right)\right]\right] \geqslant 0 \tag{17}$$

[10] As we will see, this turns out to be the price with regulatory discretion.

[11] Without this assumption the discounted future profits of the firm is infinite and it never faces a participation constraint.

Thus if $i_0 > 0$ (i.e., investment occurs), the *ex post* participation constraint at $t = 1$, (17), is relaxed compared with the *ex ante* constraint, (14). This is the source of the hold-up problem. For now from $t \geqslant 1$, the regulator can raise welfare by lowering the price to a 'reneging' price p^R for which the *ex post* participation constraint binds. By analogy with (16), at $t = 1$ this is given by $p^R < p^C$ where

$$(1 + g_n)n_0\left[\left(p^R - c\right)D\left(p^R\right) - C^*\left(w, r_f + \delta\right)\right] = 0 \tag{18}$$

The fact that $p^R < p^C$ can be shown rigorously as follows. Let $\eta(p) = -pD'(p)/D(p)$ be the price elasticity. Then differentiating the left-hand-side of (18) and (16) we have that

$$\frac{d}{dp}\left[(p - c)D(p)\right] = D(p)\left[1 - \left(\frac{p - c}{p}\right)\eta(p)\right] > 0 \tag{19}$$

since $L = (p - c)/p$, the Lerner index, must be below its monopoly level $1/\eta$. It follows that the left-hand-side of (18) and (16) are increasing in price. If investment occurs and therefore $i_0 > 0$ the right-hand-side of (18) is less than that of (16). We therefore conclude that $p^R < p^C$.

Recognizing this incentive to renege on the commitment price at time $t \geqslant 1$, at time $t = 0$ the firm will anticipate that the ex ante participation constraint (14) will not be satisfied *ex post* and will make an optimal decision not to invest. Hence without some mechanism to enforce commitment, the equilibrium with regulatory discretion will be a no-investment outcome with $i_\tau = 0$ and capital stock declining according to $K_\tau = (1 - \delta)^\tau K_0$. The corresponding discretionary regulation prices can be found by backward induction. To solve the infinite time-horizon problem we first consider a finite time horizon with terminal date T and then let T become large. Then at time $T > t$, the binding participation constraint is given by

$$n_T(p_T - c)D(p_T) - wL_T = 0 \tag{20}$$

where $K_T = (1 - \delta)^{T-t} K^*$ and $n_T = (1 + g_n)^T n_0$. Proceeding by backward induction at time $T - 1$ the two-period constraint becomes

$$n_{T-1}(p_{T-1} - c)D(p_{T-1}) - wL_{T-1} + \beta_f\left[n_T(p_T - c)D(p_T) - wL_T\right] = 0 \tag{21}$$

Combining (20) and (21) we get

$$n_{T-1}(p_{T-1} - c)D(p_{T-1}) - wL_{T-1} = 0 \tag{22}$$

and at any time $t \leqslant T$

$$n_t(p_t - c)D(p_t) - wL_t = 0 \tag{23}$$

In (23) effective labour L_t is at a level required to service n_t customers alongside a capital stock K_t. From (1) it is given by

$$L_t = \left[\frac{n_t}{K_t^\gamma}\right]^{1/1-\gamma} \tag{24}$$

Taking logs and differentiating we then have under discretion the following rate of growth of effective labour

$$g_L^D = \frac{\Delta L_t}{L_t} = \frac{1}{1-\gamma}\left[\frac{\Delta n_t}{n_t} - \gamma\frac{\Delta K_t}{K_t}\right] = \frac{1}{1-\gamma}\left[g_n + \gamma\delta\right] \tag{25}$$

which compares with a lower growth $g_L^C = g_n$ under commitment.[12]

From (23) it follows that as for large t the function $(p_t - c)D(p_t)$ eventually grows at a rate $g_L^D - g_n = (\gamma/(1-\gamma))(g_n + \delta)$.[13] It follows that the discretionary regulated price p_t^D must also grow at a rate that increases with $g_n + \delta$. Thus paradoxically the consumer loses out as a result of the opportunistic behaviour of the regulator who is not able to commit. Because of the opportunity to renege and lower the price to $p^R < p^C$, the equilibrium that results sees no investment, higher costs and eventually a *higher* and growing regulated price under discretion $p_t^D < p^C$. We summarize this section as:

Result 1 A regulator lacking a commitment mechanism who puts the same or lower weight on producer surplus as consumer surplus will hold up the investing firm and lower the regulated price after investment has been sunk. As a consequence there will be no investment and the time consistent regulatory price will rise indefinitely at a rate that increases with the growth of customers plus the depreciation rate.

2.2 The credibility problem in monetary policy

Following the seminal article by Barro and Gordon (1983) the well-known analogous problem in monetary policy is a stabilization problem in which the

[12] In many developing countries, as described by Noll (2000) and Levy and Spiller (1996) there was a chronic under-investment problem in utility industries that led to a package of reforms that includes privatization and independent regulators. This problem took the form of long waiting lists for a telephone, old facilities, and inefficient practices. This is compatible with a large and frequently increasing work force as featured in our model under discretion and no investment.

[13] However $(p_t - c)D(p_t)$ reaches a maximum at the monopoly price $p = c/(1-1/\eta)$ so eventually the participation constraint can only be satisfied if the firm closes. If we assume $\eta > 1$ is close to unity (which is consistent with empirical demand studies) then the monopoly price is large and the discretionary price will exceed it only for large t at which point capital stock on the right-hand-side of the participation constraint (23) will be very close to zero. Then with $n_t = L_t = 0$ following closure, (23) holds to a good approximation as $T \to \infty$.

monetary authority at time t sets a state-contingent inflation rate π_t to minimize a loss function

$$\Omega_0 = E_t \sum_{t=0}^{\infty} \beta^t \left[b(l_t - n)^2 + \pi_t^2 \right] \tag{26}$$

where l_t is employment (expressed in logarithms) given by an expectations-augmented Phillips Curve

$$l_t = \bar{l} + \xi[\pi - E_{t-1}(\pi_t)] - \epsilon_t \tag{27}$$

where $\bar{l}$ is the equilibrium or 'natural' level of employment, $E_t(\cdot)$ denotes rational expectations at time t and ϵ_t is a supply shock, independently distributed over time with zero mean. In (26), n is a target employment level (still in logarithms), e.g., 'full-employment'. Thus the monetary authority prefers full-employment to unemployment and zero inflation to positive or negative inflation.

For this simple, essentially static model of the economy assumed, optimal rules must take the form of a constant deterministic component plus a stochastic shock-contingent component. As for the regulation problem, these rules depend on whether the policymaker can commit, or she exercises discretion and engages in period-by-period optimization. The standard results in these two cases are respectively:

$$\pi_t = \frac{b\xi}{1 + b\xi^2} \epsilon_t = \pi^C(\epsilon_t) \tag{28}$$

$$\pi_t = b\xi u + \frac{b\xi}{1 + b\xi^2} \epsilon_t = \pi^D(\epsilon_t) \tag{29}$$

where $u = n - \bar{l}$ is the equilibrium unemployment rate (i.e., the 'natural rate' or 'NAIRU'). Thus the optimal inflation rule with commitment, $\pi^C(\epsilon_t)$ consists of zero average inflation plus a shock-contingent component which sees inflation raised (i.e., monetary policy relaxed) in the face of a negative supply shock. The discretionary policy, $\pi^D(\epsilon_t)$, can be implemented as a rule with the same shock-contingent component as the *ex ante* optimal rule. The difference is now that it includes a non-zero average inflation or inflationary bias equal to $b\xi u$ which renders the rule time-consistent. The credibility or 'time-inconsistency' problem, first raised by Kydland and Prescott (1977), can be stated simply as how to eliminate the inflationary bias whilst retaining the flexibility to deal with exogenous shocks.

3. Solutions to the two time inconsistency problems

3.1 Reputational equilibria

Suppose now that there are two types of policymaker in both the regulation and monetary policy areas, a 'strong' type who likes to commit and perceives substantial costs from reneging on any such commitment, and a 'weak' type who optimizes in an opportunistic fashion on a period-by-period basis. In a complete information setting these types are observed by the public and the strong type then pursues the commitment price rule p^C given by (16) for the price regulator or the inflation rule (28) for the monetary authority. The weak type pursues the corresponding discretionary policies (23) or (29) respectively. With uncertainty about the type of policymaker, the game is now one of incomplete information and we examine the possibility that commitment rules can be sustained as a Perfect Bayesian Equilibrium.

For both the regulator and the monetary authority we consider the following strategy profile.

1. A strong type follows the commitment rule.
2. In period t a weak type acts as strong and follows the commitment rule with probability $1-q_t$. Otherwise with probability q_t it reveals its type and must pursue the discretionary rule.
3. Let p_t the probability assigned by the private sector to the event that the policymaker is of the strong type. We can regard p_t as a measure of reputation. At the beginning of period 0 the private sector chooses its prior $p_0>0$. In period t the private sector receives the 'signal' consisting of the regulated price or the inflation set by the policymaker. At the end of the period it updates the probability p_t, using Bayes rule, and then forms expectations of the next period's regulated price or inflation rate.

In principle there are three types of equilibria to these games. If both strong and weak governments send the same message (i.e. implement the same regulated price or inflation rate) we have a pooling equilibrium. If they send different messages this gives a separating equilibrium. If one or more players randomizes with a mixed strategy we have a hybrid equilibrium. Thus in the above game, $q_t=0$ gives a pooling equilibrium, $q_t=1$ a separating equilibrium and $0<q_t<1$ a hybrid equilibrium. If $q_t=0$ is a Perfect Bayesian Equilibrium to this game, we have solved the time-inconsistency problem (see Appendix 2 for details).

To show $q_t=0$, it is sufficient to show that given beliefs by the private sector there is no incentive for a weak government to ever deviate from acting strong. This 'no deviation condition' is examined in Appendix 3 for the regulatory and monetary policies in turn. If the condition holds, then the weak authority always mimics the strong authority and follows the commitment rule. The weak regulator can then sustain optimal investment and the weak monetary authority can sustain average zero inflation coupled with optimal stabilization.

3.2 A reputational equilibrium solution to the hold-up problem

Suppose that the regulator deviates from the commitment path at time t where $K_t = K_t^*$, the optimal growing stock of capital given by (10). Investment ceases on deviation and capital stock declines according to

$$K_{\tau+1} = (1-\delta)K_\tau; \qquad \tau \geqslant t,\ K_t = K^* \tag{30}$$

Let the solution to (23), p_τ^D, be the discretionary deviation price at time $\tau \geqslant t$ following a deviation at time t from a commitment path with capital stock at K_t^*. The profile of this path for the regulated price is as follows: at $\tau = t$, the time of deviation, $p_\tau^D < p^C$ and there are welfare gains to consumers. From $\tau > t$, capital stock declines and the regulated price rises at a rate increasing with $g_n + \delta$. Eventually, at time $\tau = t+n$ periods say, the regulated price following deviation rises above the original commitment price and the consumer begins to lose out. Then the no-deviation condition is

$$\begin{aligned}&\sum_{\tau=t}^{\infty} \beta^{\tau-t}\big[S\big(p^C\big) + \alpha U\big(p^C, K_\tau^*, L_\tau^*, \big(g_n+\delta\big)K_\tau^*\big)\big]\\ &\quad > \sum_{\tau=t}^{\infty} \beta^{\tau-t}\big[S\big(p_\tau^D\big) + \alpha U\big(p_\tau^D, (1-\delta)^{\tau-t}K_\tau^*, L_\tau, 0\big)\big]\end{aligned} \tag{31}$$

where L_τ is given by (24). We can express this in terms of utility gain to the regulator or 'temptation' and a utility loss 'punishment' as in Barro and Gordon (1983). Temptation lasts for n periods during which $p_\tau^D < p^C$. Thereafter as capital stock depreciates further and $p_\tau^D > p^C$, punishment sets in and (31) can be written as

$$\begin{aligned}&\sum_{\tau=t}^{t+n} \beta^{\tau-t}\big[S\big(p_\tau^D\big) - S\big(p^C\big) + \alpha\big[U\big(p_\tau^D, (1-\delta)^{\tau-t}K_\tau^*, L_\tau, 0\big) - U\big(p^C, K_\tau^*, L_\tau^*, \big(g_n+\delta\big)K_\tau^*\big)\big]\\ &\quad < \sum_{\tau=t+n+1}^{\infty} \beta^{\tau-t}\big[S\big(p_\tau^C\big) - S\big(p^D\big) + \alpha\big[U\big(p^C, K_\tau^*, L_\tau^*, (g_n+\delta)K_\tau^*\big)\\ &\qquad\qquad - U\big(p_\tau^D, (1-\delta)^{\tau-t}K_\tau^*, L_\tau, 0\big)\big]\end{aligned} \tag{32}$$

The left-hand-side of (32) is the temptation over n periods during which $p_\tau^D < p^C$. The right-hand-side is the punishment over the remaining periods for which $p_\tau^D > p^C$. Since p_τ^D grows at a rate increasing in $g_n + \delta$, it follows that for the regulation game unless depreciation and/or the growth of customers are rapid a pooling Perfect Bayesian Equilibrium may not exist, even for β close to unity, ruling out a reputational solution to the hold-up problem in regulation.

We summarize this result as:

Result 2 Some combination of a low capital depreciation rate, a low increase in customer demand and a lower discount factor for the regulator results in the temptation to deviate from the commitment price exceeding the costs of losing reputation. Then a Perfect Bayesian pooling equilibrium with optimal investment does not exist.

Figures 1 to 5 illustrate this result. Figure 1 shows the profile of the discretionary price, p_τ^D from $\tau = 0$ given by (23), when no extra investment takes place and capital stock depreciates from its initial level K_0, and the discretionary price following deviation at time $t = 1$ after optimal investment K_1^* has occurred and capital stock depreciates from that level. These price trajectories are compared with the commitment price given by (16).[14]

In the absence of any extra investment, the discretionary price starts out above the commitment price and grows at a rate that increases with $g_n + \delta$ If deviation from the commitment price occurs at $\tau = 1$, for the first case of a low depreciation rate, $\delta = 0.025$, the regulated price drops from its commitment level of around $p^C = 1.022$ to $p_1^D = 1.015$. Then investment ceases, but as the capital stock only depreciates gradually (at 2.5% per year in Figs 1 to 3) the price remains below the commitment level for around 13 years in this simulation. This is the

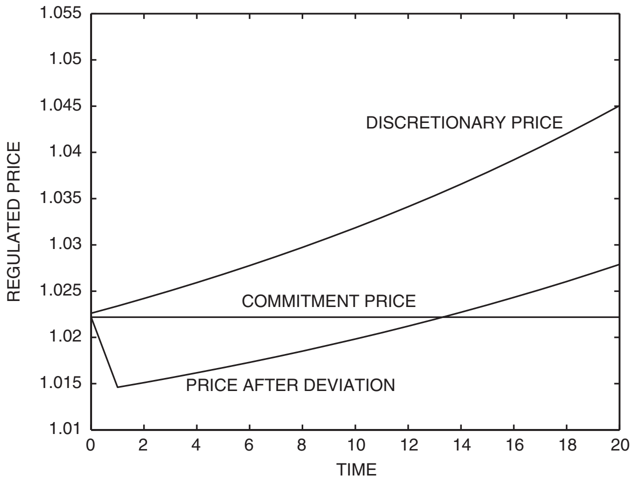

Fig. 1. Commitment price, deviation price following deviation at time 1 and the discretionary price from time 0: $\delta = 0.025$

[14] The following functional form is adopted: $D(p) = Ap^{-\eta}$ and parameter values are $\alpha = 1$, $\gamma = 0.4$, $\eta = 1.05$, $A = 30$, $c = w = n_0 = 1$, $r = 0.05$ and $g_n = 0.025$. We assume $K_0 = 0.5K_1^*$. In Figs 1 and 2, $\delta = 0.025$; in Figs 3 to 4, $\delta = 0.075$.

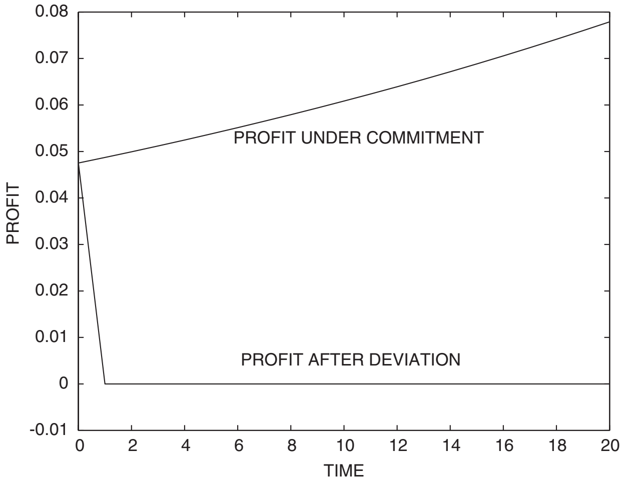

Fig. 2. Profit under commitment and following deviation at time 1: $\delta = 0.025$

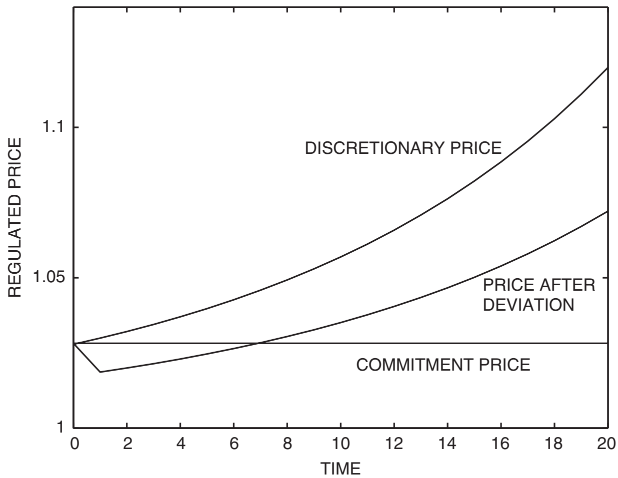

Fig. 3. Commitment price, deviation price following deviation at time 1 and the discretionary price from time 0: $\delta = 0.075$

temptation period. Thereafter in the punishment period the deviation discretionary price rises above the original commitment price and grows indefinitely.[15] From Fig. 5, the deviation condition that punishment exceeds temptation only holds for $\beta > 0.90$. Figure 3 shows the single-period profit of the firm under commitment

[15] Because profits from the final service $(p-c)D(p)$ reach a maximum at $p = c/(1-1/\eta) = 20c$ for our chosen value of η close to unity, eventually the participation constraint (23) under discretion is impossible to satisfy and the firm closes.

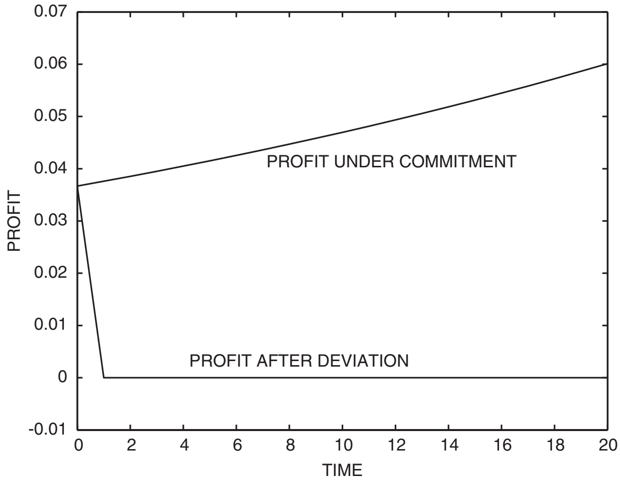

Fig. 4. Profit under commitment and following deviation at time 1: $\delta = 0.075$

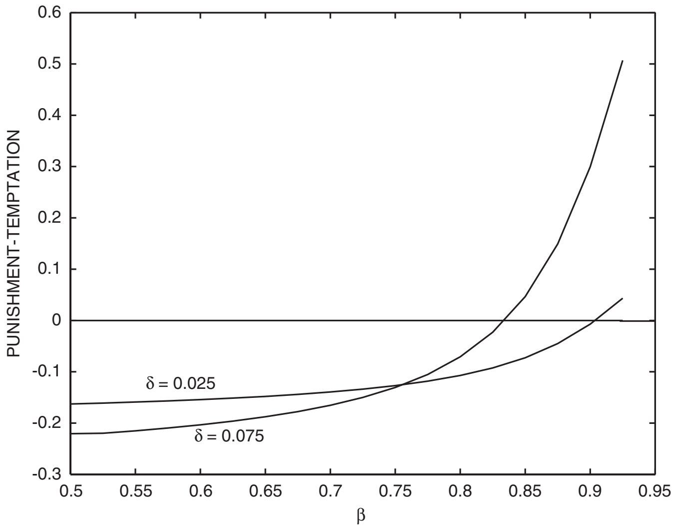

Fig. 5. The no-deviation condition (punishment > temptation) as the regulator's discount factor, β, increases: $\delta = 0.025$ and $\delta = 0.075$ compared

and following deviation. Out theory tells us that the former grows at a rate equal to customer growth. Following deviation, profit falls to zero where it is constrained to stay by the participation constraint.

Figures 3 and 4 repeat this exercise for a higher depreciation rate, $\delta = 0.075$. Now with a higher capital stock and growing demand the deviation price drops by proportionally more but thereafter grows faster and from Fig. 5, the temptation period decreases to around seven years and the deviation condition holds for $\beta > 0.87$. An interesting feature of this simulation is that for a low discount factor β for the regulator, the incentive to deviate is higher for the high δ case compared with the low δ case but as β increases these two curves in Fig. 5 cross. The reason for this is that for the lower depreciation rate the temptation period is longer and a higher discount factor is required for the full impact of this incentive to deviate to be felt. Eventually at a sufficiently high β it becomes harder to sustain the optimal investment for a low δ which corresponds to a higher optimal capital stock.

Appendix 3 works through the analogous reputational solution to the monetary policy game. We obtain contrasting results for the lower bound on β necessary to sustain the commitment monetary rule. Unlike the deterministic model in the regulation game,[16] monetary policy involves stabilization in the face of exogenous supply side shocks. If these shocks are small we can compare like with like. Then a sufficient (and not even necessary) condition for a monetary authority to be able to sustain the optimal policy as a reputational equilibrium is $\beta > 0.5$ compare with a lower bound for β for the regulation game in the interval $[0.83, 0.92]$ for $\delta \in [0.025, 0.075]$ in our simulations. Thus we have the result that a reputational solution to the hold-up problem is much more difficult that for monetary policy. The reason for this is that with monetary policy temptation lasts for only one period, whereas as we have seen in the regulation game temptation lasts for many periods though this interval falls as the sum of the depreciation rate and the demand growth rate rises. We summarize this comparison as:

Result 3 A reputational solution to the hold-up problem is more difficult to obtain in the utility regulation case than for the monetary policy case because, for the latter, temptation lasts for only one period, whereas for the former with slow capital depreciation and consumer growth temptation can last for many years.

3.3 Related literature on the hold-up problem

There are very few previous studies that analyze to what extent is regulation sustainable in the presence of sunk investments, without additional institutional restraints. Newbery (1999, ch. 2), and Salant and Woroch (1992) present two other infinite horizon games of regulation that examine this issue, and hence are related to our paper. These two infinite horizon models allow the regulator (who basically represents the consumers) and a regulated firm to alleviate the under-investment problem by sustaining a cooperative equilibrium in which the firm

[16] A stochastic element can be easily introduced into the regulation game as for the monetary game and this will further undermine the prospect of a reputational equilibrium. For example suppose that the scrap value of a unit of capital s is replaced with $s_t = s - \zeta_t$ at time t. Then as for the supply shock in the monetary game, a high realization of ζ_t will relax the *ex post* participation constraint of the firm further and increase the temptation of the regulator to renege on the commitment price.

invests and the regulator sets a price that allows for the recovery of sunk investment costs. The structure of these games is based on the same kind of Folk Theorems that are used to explain collusion between oligopolists. This same structure, in which there is complete information, was used by Barro and Gordon (1983) to find conditions under which the inflation bias could be alleviated in an infinite horizon monetary policy game.

One of the problems of these infinite horizon games with complete information based in the Folk Theorem is that the cooperative equilibrium is just one of many possible equilibria. In fact, the no-investment/no-recovery outcome remains a possible solution, and forms the conflict point of the game. If coordination is possible, parties would coordinate on the efficient outcome. But then the equilibrium is not 'renegotiation-proof' and this questions the credibility of trigger-strategy equilibria, even though they are subgame perfect.[17] Barro (1986) presents a reputational model of monetary policy, where the private sector is uncertain about the monetary authority type, that avoids this problem. In this context, reputation for commitment can be sustained under certain conditions, which may alleviate the inflation bias. The relationship of our model to Newbery and Salant/Woroch is the same as between Barro (1986) and Barro and Gordon (1983). We introduce incomplete information about the type of regulator, which allows for a reputational equilibrium to be sustained under some conditions. Apart from the theoretical problems of trigger-strategy equilibria alluded to, given that there are few doubts that sustaining the reputation of the regulators is an important ingredient in the modern institutions that govern the economy, we believe that truly reputational games are a preferable way of modelling price regulation.

Our basic model differs from Newbery's in two important respects: first we allow both for growing demand from increasing numbers of customers, but also for variable demand, whereas in his model demand is inelastic (it varies with two possible states of nature, but it does not vary with price). This implies a crucial difference between his results and ours when the profits of the firm have the same weight in the regulator's objective function as the consumers' surplus. When demand is inelastic, allocative efficiency plays no role, so that with a weight of unity for profits in the objective function, productive efficiency may be achieved by covering the sunk investments costs. However if, as in our model, demand is elastic, when the weight of profits and consumers' surplus is the same, allocative efficiency calls for price equal to marginal cost, which does not cover the fixed costs, and hence the firm loses the incentive to invest.

[17] See al-Nowaihi and Levine (1994) who, in the context of the monetary policy game, argue for a refinement they term 'chisel-proofness' to resolve this difficulty. It should be noted that the renegotiation-proof equilibria used in repeated games differ from the concept used in the contract literature. They do not necessarily involve contracts or even negotiation, but should be interpreted as allowing players to recoordinate their expectations of strategies. For this reason the term 'recoordination-proof' equilibria is often used instead.

A second difference between our model and Newbery (1999, ch. 2) is that we fully incorporate depreciation as an explicit variable of our set-up. Although Newberry acknowledges the role played by depreciation, he just mentions that depreciation costs can be interpreted as part of the cost of capital. He rightly argues that the size of the capital costs depends on the capital intensity of production and also on the length of the period over which capital depreciates and needs to be replaced or augmented: 'If this period is long, then the regulator gains a considerable advantage for consumers before having to incur the replacement costs, but if short, then the benefits of reneging are transient, but the costs go on forever.' He thus reaches the conclusion that high rates of depreciation or obsolescence help sustain the regulatory compact, and this is one of the reasons why 'privatizing telecoms is therefore likely to be easier than privatizing electricity.' We develop this insight further in our model, by making depreciation an explicit and fundamental ingredient of our set-up, and a key issue in the comparison between monetary policy and utilities regulation.

The explicit treatment given to depreciation is a common feature of our model and Salant and Woroch (1992), although ours is a reputational model where the firm is uncertain about the regulatory type, and we emphasize the comparison with monetary policy. They do not allow for growing demand nor do they explore the possibility that problems with sustaining the cooperative equilibrium can be solved by delegation.

3.4 Rogoff delegation

The alternative and, increasingly, the preferred solution to the monetary policy time inconsistency problem has been for governments to delegate the operation of monetary policy to a goal-independent central bank (CB) with powers of discretion. In the context of our model goal-independence means that the CB sets and perfectly achieves its own inflation rate in accordance with its own welfare loss function. The theoretical case for such a policy has been set out by Rogoff (1985) among others. Rogoff proposed a second-best solution to the credibility problem involving a trade-off between low average inflation and effective monetary stabilization policy. The solution is to delegate monetary policy to an independent central bank with an appointed board chosen to be 'conservative', in the sense that they assign a higher priority to low inflation than that of the representative government. An optimal choice of conservatism will then see bankers appointed who deliver low average inflation, but who are not so over-conservative as to prevent monetary stabilization.

If the main purpose of independent central banks is to eliminate the temptation to engage in surprise inflation, the main purpose of independent regulatory agencies is to solve the hold-up problem and eliminate the temptation to engage in a surprise cut in the regulated price, thereby supporting investment. As set out above, the underlying rationale for an independent utilities regulator and an independent central bank is extremely similar. This suggests that there may well be similarities between the proposed ways of creating an institution which can establish and maintain a credible reputation for making and keeping commitments in a way that governments find extremely difficult to do. Surprisingly, however, there has been relatively little written on the Rogoff-delegation approach in regulation.[18]

We now turn to the formalization of the delegation game in regulation. The timing of events is as follows:

1. At time $t=0-$, the government delegates price regulation to an independent regulator with preferences

$$\Omega = \sum_{\tau=t}^{\infty} \beta^{\tau-t}\left[S(p_\tau) + \alpha U_t\right] \tag{33}$$

where $\alpha > 1$ measures the extent to which the regulator is 'pro-industry'.
2. At time $t=0$, the firm chooses its investment plan $i_\tau; \tau \geqslant 0$.
3. In every period $t>0$, the regulator chooses the regulated price to maximize Ω_t subject to the *ex post* participation constraint

Again we first consider a finite time horizon with terminal date T. Solving by backward induction for a perfect equilibrium, at stage 3, time T, the independent regulator solves the problem:

$$\text{Given } K_T L_T \text{ and } i_T \text{ maximize w.r.t } p_T \quad \left[S(p_T) + \alpha U_T(p_T, K_T, L_T, i_T)\right] \tag{34}$$

subject to $U_T(p_T,K_T,L_T,i_T) = n_T(p_T - c)D(p_T) - wL_T - i_T \geqslant sK_T$. The solution to this problem is standard (see Appendix 4) and takes the form of the Lerner price given by

$$p_T^L = \frac{c\alpha\eta}{\alpha(\eta-1)+1} = p^L(\alpha) \tag{35}$$

if the participation constraint does not bind which happens when α is sufficiently large. Then as α rises it reaches a point where

$$p^L(\alpha) = p^C \tag{36}$$

and the regulator is sufficiently pro-industry that, even with discretion, it chooses a price at the commitment level that offers the firm a return on its initial capital investment at time $t = T, T-1, \ldots, 1$. Solving for stage 2 the firm then invests

[18] Rogoff-delegation has been proposed in the environmental regulation context by Spulber and Besanko (1992). Where firms have private information, Levine and Rickman (2001) examine the role of delegation as a means of ameliorating both the 'ratchet-effect' associated with incentive contracts and the hold-up problem.

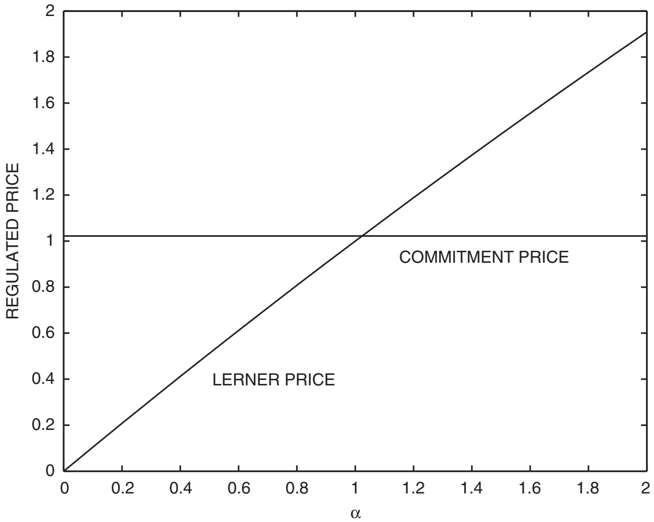

Fig. 6. Lerner and commitment prices as α increases

at the optimal level $t_0 = K_t^*, i_T = (g_n + \delta)K_t^*$; $\tau \geqslant 1$ and the hold-up problem has been solved. Figure 6 illustrates this result which we summarize as:

Result 4 A pro-industry regulator with $\alpha > 1$ sufficiently high and acting with discretion will be able to credibly implement the socially optimal regulatory price with optimal investment.

4. Commitment to rules versus Rogoff delegation

Our analysis shows that a non-benevolent regulator or monetary authority with a discount factor β far less than unity because, for instance, of its short-term electorial priorities would find it difficult to credibly follow an optimal commitment rule. This provides one rationale for independent regulators or central banks: by depoliticizing policy and delegating control to an independent authority which free of electoral pressures can take a long-term view, it is then possible for the optimal but time-inconsistent rule to be credibly pursued as a reputational equilibrium. However our results show that this reputational solution is intrinsically more difficult for price regulation in network industries if customer demand is growing slowly and the depreciation rate of capital invested in the network is low. Then even a benevolent regulator with a discount factor close to unity would find that the reputational mechanism is insufficient to sustain an optimal regulatory price with optimal investment.

Another problem with optimal commitment rules that applies to both regulation and monetary policy is they are generally complex and difficult to monitor, a feature that is essential for the possibility of a reputational equilibrium. With uncertainty, revisions of the rule will be indistinguishable from reneging unless the basis for these revisions are completely transparent. For instance the firm may have private information regarding costs. Then any commitment mechanism in place will lack credibility and the firm may still under-invest. These features of optimal rules have been understood by macro-economists for some time and attention has focused on 'simple' sub-optimal but easily monitored feedback rules, such as the Taylor Rule, which feed back on a limited number of easily observed macro-economic variables, typically output, and inflation.[19]

These considerations provide support for a Rogoff-delegation solution to the hold-up problem in reputation. The great advantage of delegation is that, in contrast with commitment rules of either the optimal or sub-optimal variety, the policymaker retains discretionary powers and can base policy on the latest forecasts and information available. In the context of regulation a sufficiently pro-industry regulator can implement the Lerner price p^L based on the latest estimates of the underlying parameters.

One practical problem with delegation is that the the government has to find a regulator or central banker with the right weight α on profit or b on output in their respective objective functions. However, for a typical OECD country one can think of the policy framework in two ways: as literal or 'as if' Rogoff delegation. In the case of literal delegation a goal-independent regulator or central bank evolves towards optimally chosen conservative agencies. This may possibly involve reputation-building where a reputation for independence is established over time. In the case of 'as if' Rogoff delegation, an independent agency has a duty to act in a relatively conservative or pro-industry way (e.g., via obligations set out in the relevant law). One may think of the agency as 'goal-dependent', in the sense that its objectives (in the form of utility defined over outcomes) are given to it by policymakers. However, the agency has the legal right to set the instruments under its control in a discretionary manner, using all available current information.[20] For central banks, the US Federal reserve with its emphasis on the personality of its head corresponds more to literal Rogoff-delegation and the European Central Bank (ECB) is a good example of 'as if' delegation.[21]

[19] See Levine and Currie (1985), Currie and Levine(1993). In the context of both the general political economy and regulation literatures, it is recognised that transaction costs are a significant determinant of the evolution of political and regulatory institutions and provide a rationale for simple rules, regulations and laws (see Dixit, 1996; Vogelsang and Spiller, 1997; Estache and Martimort, 1999).

[20] In monetary policy Persson and Tabellini (2000, p.444) argue as follows: 'A better interpretation may be that at the constitutional stage, society drafts a Central Bank statute spelling out the institution's mission. The parameter b then reflects the priority assigned to price stability relative to other macro-economic goals.'

[21] With 'as if' Rogoff delegation where the desired trade-off between the conflicting objectives is given to the office-holder as a duty that must be fulfilled, the choice of decision-maker can be made purely on the basis of technical and other ability and not on ability plus a prediction of whether the chosen person is (and will remain) optimally conservative or pro-industry. The Bank of England (BoE) is goal-dependent and could be seen as a form of 'as if' Rogoff delegation.

In an uncertain world where the economic environment is constantly changing one might expect either of these forms of policy regime to outperform any fixed rule that forbids discretion. As Persson and Tabellini (2000) argue for the case of central banks, since instrument independence is a necessary condition for delegation to work, we should expect such a strategic setting of weights in the objective function to work better if combined with institutional and legislative features granting independence of the regulatory agency and shielding it from short run political pressures.

To summarize, the choice of approach to the time-inconsistency problem for both regulatory and monetary policies is between the second-best alternatives of commitment to a sub-optimal simple commitment rule either fixed and based only on information on the economy available at the time the rule is announced, or state-contingent but in a very limited and transparent way, or delegation to an independent, literally conservative agency (or, in our preferred interpretation, 'as if' Rogoff delegation) who follows a sub-optimal discretionary policy based on all the latest information on the economy. The former requires a reputational mechanism to sustain and this is intrinsically more difficult for price regulation.[22]

Delegating to regulatory institutions that place a higher weight on industry profits than society may certainly amount to relocating the commitment problem, but not really solving it. We conjecture however that defining the new institutions in primary law makes it more costly to renege on the whole setting than it is to renege for a representative regulator. In any case, it is not easy to strategically delegate into agencies that give more weight to firm's rents than to consumers, although we have shown that this is iso-morphic to placing due weight on the interests of future consumers. Some temptation to renege on the regulatory package remains, and again this temptation will be higher for industries with lower depreciation and demand growth rates.[23]

In public utilities regulation in OECD countries, it is common that the government establishes the policy to be followed. Primary legislation, among other provisions, usually prescribes that the regulator has to guarantee the financial viability of regulated firms. Then the regulator acts in a discretionary fashion to set a previously defined set of instruments using all available current information.

[22] In some contexts (see for example Guasch and Spiller, 1999), it is argued that countries with limited institutional capacity should carry out regulation by simple, minimum discretion or, if possible, by reliance by the regulatory agency on contract enforcement. However, recent appraisals of actual regulatory reforms point out that regulatory governance arrangements based on rigid rules were not robust to unforeseen contingencies. See Joskow (2001) for the case of California, Fischer and Galetovic (2000) on problems derived from rigidity in Chilean electricity, and Abdala (2000) on post-privatisation conflicts in Argentinian telecommunications.

[23] Comparing telecommunications and electricity (or other regulated industries with lower depreciation and demand growth rates than telecommunications), we predict that delegation is more necessary in electricity (because commitment rules are difficult to sustain through reputation) but for the same reasons delegation is more difficult to sustain in practice.

In this sense, regulators such as the British utility regulators are goal-dependent, required to behave with a specific objective function, and therefore constitute an example of our 'as if' Rogoff-delegation.[24] In practice, the need to constrain the discretion of regulators stems not only from the need to impose on them a duty to behave in a sufficiently pro-industry way, but also from the need to enforce accountability and promote legitimacy and market credibility. We conjecture that these features could be captured in a model that expands our setting to take into account asymmetric information and non-benevolence. These features would probably make independent agencies more necessary, but the need to constrain their discretion more acute.[25]

5. Discussion of empirical evidence

In this section we discuss how the empirical literature relates to our model and we suggest some directions for research on regulatory institutions. There is a very large literature on the economic impact of central bank independence.[26] The general consensus is that countries which assign monetary policy to an independent central bank have lower and less variable rates of inflation. This is a recurring result for developed and developing countries. 'Independence' is typically measured in such studies by an index of governance, averaging over a number of components although, for developing countries the turnover rate of central bank governors has been a powerful indicator of independence.[27]

For utility regulators, a growing body of sectoral or regional studies of both a quantitative and qualitative kind do comprise a substantive body of work that is largely consistent with our own line of inquiry.[28] The cross-national literature is smaller. There have been many case studies, but so far relatively few studies investigating these issues using formal statistical analysis.

In general, the focus of the cross-national econometric studies has been on the role of independent regulators in stimulating private investment (for telecoms, typically proxied by the number of mainlines or mainlines per 100 inhabitants), primarily in developing countries. In general, the data for telecoms is better and there is more experience with telecom regulation than for other utilities. However, some results have recently become available on the impact of regulation (and regulatory governance) on electricity generation investment.

[24] Indeed critics of UK regulatory processes regularly maintain that regulators have too much discretion.

[25] Laffont (2000) presents a model where the risk of capture makes it socially optimal to reduce regulatory discretion so that the stakes of regulation are low.

[26] Excellent surveys are to be found in Eijffinger and De Haan (1996) and Berger *et al.* (2000).

[27] In addition, Fracasso *et al.* (2003) and Geraats (2002) support the positive impact of informational Central Bank transparency on macro-economic outcomes.

[28] See for example Melody (1997), Berg (1999), Guasch and Spiller (1999), Delmas and Heiman (2001), Monaldi (2001), and Mueller (2001).

The focus of this emerging literature on developing country private investment in telecoms and similar industries is appropriate and corresponds to the concerns of this paper. There is no question that these countries have considerable unsatisfied demand and that they face major difficulties in inducing sufficient investment to meet the capacity needs—at least at an acceptable cost of capital. Hence, the role of the regulator is crucial in providing the credibility that will support the necessary investment flows.

None of the econometric studies undertaken have data on regulatory processes or practice; the only regulatory data that exists is for the legal framework, for example whether there is a regulatory law, whether the regulator is formally independent, how it is funded, etc. A major task for future research is to include evidence on regulatory processes and practices and how they evolve over time, for example the percentage of regulatory agency commissioners (or office heads) whose tenure is ended prematurely. The absence of data on regulatory processes and practices is unfortunate given that the evidence suggests that, in developing countries, the quality of the law typically exceeds the quality of its application and enforcement so that the quality of the legal framework exaggerates the quality of regulation in practice.[29] It means that coefficient estimates on the regulatory variable are likely to be downward biased because of an errors-in-variables problem.[30] These problems must be added to the one of finding a common desirability of outcomes across a large set of countries, to which we alluded in the introduction of the paper.

In spite of these difficulties, Wallsten (2002) finds that installing a regulatory agency separate from the relevant Ministry before privatisation is positively and significantly associated with several indicators of investment. Wallsten's regulatory variable was a simple time-dated dummy on whether or not a regulator had been enacted in the law. The same is true of the regulatory variable in the study of 86 non-OECD countries by Fink *et al.* (2002). This study finds that the existence of an independent regulatory agency significantly augments the (positive) effect on mainline penetration of competition and privatisation.

Gutierrez (2003) and Gual and Trillas (2004) are the first studies to associate indices to regulatory institutions, in the spirit of the literature on Central Bank independence. Gutierrez (2003) estimates the effect of a seven-item index of regulatory governance on mainline density and efficiency for 22 Latin American and Caribbean countries. He finds that both the index and the three main subcomponents have a positive and significant effect (at the 1% level) on mainline penetration, after controlling for competition and privatisation. This holds for both static and dynamic models and the estimated coefficients are robust to corrections for potential endogeneity.

[29] See Stern and Holder (1999).

[30] In addition, it can be very difficult to establish the impact of regulation per se since the law that establishes the regulator is frequently the same one that provides for competition and /or privatisation (or it is enacted close in time to laws on these other factors).

Gual and Trillas (2004) present and use an index of regulatory independence in telecommunications for 37 countries, constructed using principal components techniques and thus taking advantage of the correlation between the original variables. They find that legal independence is more likely in countries with a larger incumbent and that legal independence is more frequent in countries with worse rule of law measures. They take this as evidence that incumbent firms lobby for independent agencies and that independence is a substitute for other ways to commit not to expropriate the incumbent's quasi-rents.[31] They find that independence has a positive but not significant impact on network penetration, using International Telecommunications Union data.[32]

More recently, Cubbin and Stern (2004) use a four-component index of regulatory independence to estimate the effect of regulation on investment in electricity generation in a sample of 28 developing countries for the period 1980–2001. They estimate fixed effects panel data models similar to those of Gutierrez (2003). They find that the impact of a maximum index score (ie a regulator established by primary legislation, autonomous, funded from licence fees or similar and with freedom in setting pay) is, on average, to increase expected long-run per capita generation capacity levels by around 15–25%. This is the predicted increase relative to an otherwise average developing country having electricity regulation by a ministry without any supporting law.

However, as one might expect, the estimated regulatory effects take some time to build up. The estimated long-run impact of a regulator established for less than 12 months on *per capita* generation capacity was zero; whereas for a regulator (autonomous and/or ministry) established at least three years, it was in the 25–35% range. Similarly, a simple quadratic formulation suggested that the long-run impact continued to increase for over 10 years. Finally, lags appear to be long. Hence, the results from an error correction model showed that only about 12% of the expected long-run regulation effect on generation capacity levels could be expected to occur in the first year. All of these results provide support for the expectation that considerable time is needed (a) to build up regulatory capacity; and (b) for the regulatory agency to establish its reputation vis-à-vis investors.

Nevertheless, the empirical literature on testing whether (and, if so, how and why) utility regulatory agencies help alleviate the time inconsistency problems associated with private investment is as yet in its infancy relative to the independent CB literature. Nevertheless, the relevant empirical literature is increasingly providing strong evidence that regulatory independence has a positive impact

[31] In the case of electricity, the positive effect of political constraints on infrastructure investment is shown to be operative only in the presence of substantial interest group competition from industrial users of electricity (see Henisz and Zelner, 2002). This is also consistent with a positive correlation between regulator independence and regulators being pro-industry.

[32] However, since most of the regulatory agencies in these data sets were created in the late nineties, there are still too few data points to claim that this evidence is conclusive.

on investment and in alleviating the difficulties that developing countries have in attracting private sector infrastructure investment at an acceptable cost of capital.[33] This evidence is strongly supportive of the arguments of our paper even if not a formal test of them.

Of course, infrastructure regulators—in developing as well as developed countries—need to balance their role in supporting investment with their role of protecting consumers against monopolistic exploitation. Capture is a threat in all environments. However, in many countries, the risks to ensuring that the majority of citizens have access to such services more often that not comes from over-protection of current consumers relative to future consumers and investors.

6. Conclusions

Our argument may be summarised as follows:

1. Both in regulation and central banking a reputational equilibrium (i.e. a pooling Perfect Bayesian Equilibrium) will not exist if the policymaker is short-sighted. This provides one rationale for delegation to independent agencies free of short-term electoral pressures.
2. However even with benevolent (i.e., long-sighted) regulators, a solution to the hold-up problem in the form of a reputational equilibrium is undermined if the capital depreciation rate and growth rate of customer demand are low.
3. For both regulation and monetary policy, flexibility makes commitment rules difficult to monitor for deviation. This undermines reputational equilibria further unless they take the form of simple but sub-optimal rules.
4. These considerations suggest we may need an alternative solution to the credibility (hold-up) problem in price regulation. We propose 'as if' Rogoff-delegation to a relatively pro-industry regulator as one such alternative.

Of course, there are other significant differences between the tasks faced by independent central banks and independent regulatory agencies. The most important is that regulation (at least in some network industries such as telecommunications) is inherently about the monitoring and enforcement of the behaviour of commercial (and potentially competing) companies according to licence conditions or equivalent obligations. Monetary policy is not primarily concerned with the regulation of banks. In consequence, regulation must operate within a general competition framework and may in time be replaced—at least in some countries—by general *ex post* competition policy.[34] A further crucial issue is that

[33] This is not the same as evidence that relatively pro-industry regulators or conservative central bankers have a positive impact (this is a common feature in both literatures), which suggests the need to study the duties and procedures of regulators and their relationship with protecting industry investors. However, as reported above, both Gual and Trillas (2004) and Henisz and Zelner (2002) provide preliminary evidence that independent agencies are indeed relatively pro-industry.

[34] These issues are discussed in Vickers (2002).

the history of telecoms and other utility service regulatory agencies is very limited, particularly outside the US. In contrast, a significant number of countries still have very clear memories of hyper-inflation and the damage it causes. For many other countries there is a greater understanding of the need to maintain a low inflation rate through the relationship between monetary stability, low inflation and a good economic growth performance.

Delegation into a relatively pro-industry regulator should occur in a context of discipline and accountability. There are obvious disadvantages of regulatory capture, for example that it may lead to allocative inefficiency and that it undermines the legitimacy and the sustainability of the regulatory package. That is why delegation into relatively pro-industry regulators should be carefully laid out in regulatory laws and processes so that consumers perceive that regulatory institutions are designed in their long run interest.

The theoretical arguments and the emerging empirical literature on regulatory governance suggest strong potential benefits from well-founded regulatory arrangements with proper and transparent procedures that will support limited and accountable discretion. The next task is to develop the empirical assessment of these benefits, using data on regulatory processes or practice in the field of utility regulation.

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Appendix 1

The firm's investment problem

To carry out the minimization of expected costs given by (7) with respect to $\{i_t, L_\tau\}$, $\tau \geqslant 1$ given (3), (1) and (6) form a Langrangian

$$\mathcal{L} = \sum_{\tau=0}^{\infty}\left[wL_T + i_\tau + \mu_\tau(K_{\tau+1} - (1-\delta)K_\tau - i_\tau) + \eta_\tau\left(n_\tau - K_\tau^\gamma L_\tau^{1-\gamma}\right)\right] \qquad \text{(A.1)}$$

where μ_τ and η_τ are Lagrange multipliers. The first-order conditions for a minimum are

$$L_\tau : w - \eta_\tau(1-\gamma)\frac{\eta_\tau}{L_\tau} = 0 \tag{A.2}$$

$$i_\tau : 1 = \mu_\tau \tag{A.3}$$

$$K_\tau : \frac{\mu_{\tau-1}}{\beta_f} - \mu_\tau(1-\delta) + \mu_\tau\gamma\frac{n_\tau}{K_\tau} = 0 \tag{A.4}$$

Eliminating η_τ and μ_τ from (A.2) and (A.3) and putting $\beta_f = 1/(1+r_f)$, (A.4) gives (8).

Appendix 2

Details of the perfect Bayesian equilibrium

The concept of a Perfect Bayesian Equilibrium (PBE) imposes the following three requirements:[35]

1. At each information set the player with the move must have a belief regarding which node has been reached.
2. Given their beliefs at each information set the current move and subsequent strategies must be optimal given the beliefs and subsequent strategies of the other players. This condition is satisfied following deviation from the commitment rule because at such nodes the policymaker follows a time-consistent discretionary policy.
3. Beliefs are determined by Bayes' rule and players' equilibrium strategies.

Let ρ_t be the probability that the policymaker is of the strong type in period t. This probability is updated by Bayes rule in period $t+1$ as follows.

- Suppose that the government deviates from its commitment rule in period t. Since a strong government has no incentive to deviate, the private sector then knows that the government must be of the weak type and therefore sets $\rho_{t+1} = 0$.
- Suppose that the government does not deviate in period t. The private sector then infers that the government might be strong or it might be a weak government mimicking a strong government with probability $1 - q_t$. By Bayes rule the first possibility is given by

$$\Pr\big(\text{tough}|\text{commitment rule}\big) = \frac{\Pr\big(\text{commitment rule}|\text{tough}\big)\Pr\big(\text{tough}\big)}{\Pr(\text{commitment rule})} \tag{B.1}$$

On the right-hand-side of (B.1) we know that $\Pr(\text{tough}) = \rho_t$ (the prior at time t) and that $\Pr(\text{commitment rule}|\text{tough}) = 1$. The denominator is given by

$$\begin{aligned}\Pr\big(\text{commitment rule}|\text{tough}\big)\Pr\big(\text{tough}\big) &+ \Pr(\text{commitment rule}|\text{weak})\Pr(\text{weak}) \\ &= 1 \times \rho_t + (1-q_t)(1-\rho_t)\end{aligned}$$

[35] See Fudenberg and Tirole (1992, ch. IV).

Hence if there is no deviation from the commitment rule we have the updated posterior probability given by

$$\rho_{t+1} = \frac{\rho_t}{1-(1-\rho_t)q_t} > \rho_t \qquad \text{if } q_t \neq 0 \tag{B.2}$$

Otherwise if deviation occurs, $\rho_{t+1}=0$. In a pooling equilibrium $q_t=0$ and $\rho_{t+1}=\rho_t$ and the weak policymaker always mimics the strong type. In Section 3.2 for the regulation game and in Appendix 3 below for the monetary game we show that given these beliefs of the private sector $q_t=0$ is optimal for the weak policymaker.

Appendix 3

Comparison with the reputational solution to the monetary policy problem

In this repeated game, using (27) and (26), at time t the policymaker minimizes an expected intertemporal loss function given by

$$\Omega_0 = E_0\left[\sum_{t=0}^{\infty} \beta^t \left\{b[\xi(\pi_t-\pi^e)-\epsilon_t-u]^2+\pi_t^2\right\}\right] \tag{C.1}$$

where β is a discount factor.[36] Let ρ_t the probability assigned by the private sector to the event that the monetary authority is of the strong type. Suppose that the weak type acts as weak with probability q_t but mimics a strong type with probability $1-q_t$. For a strong type prior to the shock, $\pi_t^e=0$ whilst for a weak type $\pi_t^e=b\xi u$. Hence private sector expectations of inflation, given ρ_t and q_t are

$$\pi_t^e = \rho_t \times 0 + (1-\rho_t)q_t(q_t b\xi u + (1-q_t)\times 0) = (1-\rho_t)q_t b\xi u \tag{C.2}$$

A sufficient condition for the optimal commitment rule to be sustained as a perfect Bayesian equilibrium is that given these beliefs by the private sector there is no incentive for a weak government to ever deviate from acting strong. The no deviation condition is derived as follows. Let $\bar{\pi}=b\xi u$ be the inflationary bias. At time t given expectations $\pi_t^e=(\pi^C)^e=0$, the one-period gain in the interval $[t,t+1]$ from deviating, or temptation, is given by:

$$b\left[\xi\left(\pi^D(\epsilon_t)-\left(\pi^C\right)^e\right)-\epsilon_t-u\right]^2+\pi^D(\epsilon_t)^2 - b\left[\xi\left(\pi^C(\epsilon_t)-\left(\pi^C\right)^e\right)-\epsilon_t-u\right]^2+\pi^C(\epsilon_t)^2]$$

From time $t+1$ onwards, given the strategy profile the loss from deviating or the punishment is given by

$$E_0\left[\sum_{\tau=t+1}^{\infty} \beta^{\tau-t} b\left\{\left[\xi\left(\pi^D(\epsilon_\tau)-\left(\pi^D\right)^e\right)-\epsilon_\tau-u\right]^2+\pi^D(\epsilon_\tau)^2 \right.\right.$$
$$\left.\left. -b\left[\xi\left(\pi^C(\epsilon_\tau)-\left(\pi^C\right)^e\right)-\epsilon_\tau-u\right]^2+\pi^C(\epsilon_\tau)^2\right\}\right]$$

[36] This analysis is essentially a generalization of the deterministic treatment of Barro (1986) to a stochastic environment.

As for the regulation game, the no-deviation condition for a pooling equilibrium is then that punishment must exceed temptation. However, an important difference between the reputational equilibria in monetary and regulation policy is now apparent. Unless capital stock depreciates completely within a period, temptation in the regulation game lasts for more than one period and, indeed, if depreciation is at a low rate it can last for very many periods. By contrast in monetary policy game we saw that temptation only lasts for a single period. Substituting for the rules from (28) and (29) after some manipulation we arrive at the no-deviation condition

$$\epsilon_t < \frac{u(1+b\xi^2)}{2}\left[\frac{2\beta-1}{1-\beta}+b\xi^2\right] \tag{C.3}$$

For bounded shocks within the interval $[-v, v]$ a sufficient condition for a pooling PBE is therefore

$$\frac{v}{u} < \frac{2\beta-1}{1-\beta} \tag{C.4}$$

Result (C.4) can be used to assess the feasibility of a solution to the credibility problem of monetary policy by reputational effects. For small shocks ($v \simeq 0$), this condition implies that $\beta > \frac{1}{2}$ is sufficient to sustain a reputational solution. How large do shocks need to be to overturn this result? Consider an annual time interval (i.e., the inflation target is set annually). Suppose that the monetary authority is benevolent and adopts the same rate of discount as the private sector. A plausible value for this rate is $r = 5\%$ per annum. Then $\beta = 1/(1+r) = 0.95$ and the condition becomes $v/u < 180$ i.e., the shock (as a proportion of GDP) must not exceed $180\times$ the unemployment rate, not a stringent one. One must conclude that for a benevolent monetary authority with a rate of discount the same as that of the private sector, then for any conceivable upper bound on the shock, there exists a unique pooling PBE to this game and the monetary policy credibility problem has been solved.

Appendix 4

Rogoff delegation: the Lerner price

Suppose that the participation constraint of the firm does not bind. Then the regulator maximizes $[S(p_T) + \alpha U_T(p_T, K_T, L_T, i_T)]$ with respect to p_T given the decisions of the firm K_T, L_T and i_T and therefore $n_T = K_T^{\gamma} L_T^{1-\gamma}$. Differentiating with respect to p_T and using the definition of the consumer surplus, (13), the first-order condition for this problem is given by

$$n_T\big[-D(p_T) + \alpha((p_T - c)D'(p_T) + D(p_T))\big] = 0 \tag{D.5}$$

Putting $\eta = -p_T dD(p_T)/Ddp_T$, and rearranging this gives an expression for the Lerner index $L_T = (p_T - c)/p_T$:

$$\alpha[1 - \eta L_T] = 1 \tag{D.6}$$

from which (35) is obtained. From this result we can see that the Lerner price is an increasing function of α. Given n_T, K_T, L_T and i_T, from (19) U_T is increasing in p_T. Therefore there must be a sufficiently high value for α at which the participation constraint ceases to bind and the regulator chooses the Lerner price. Then as α increases further, the Lerner prices reaches the commitment price and the hold-up problem is solved.