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Abstract

We examine regulation as a repeated game between a regulator and a utility facing a Markovian sequence of demands. Sunk capital would be expropriated by a regulator concerned only with the short-run interests of consumers. There exist rate of return regulatory policies supporting efficient investment paths with zero expected profits as subgame perfect Nash equilibria, but these policies must under-reward capital in some states of the world. Carefully designed nonlinear price regulation can improve on these equilibrium outcomes, although at higher consumer cost, and only if state-contingent transfers are feasible.

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Regulation Games

by

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I. Introduction

The centerpiece of regulation for investor–owned public utilities is the rate of return model. The model derives its legitimacy from a series of judicical precedents, which prescribed that a regulated utility is entitled to a "fair return upon the value of that which it employs for the public convenience" (*Smyth v. Ames*, 1898). Despite a distinguished lineage, the rate of return model has been soundly criticized from the perspective of both normative and positive economics. Its incentives to choose production techniques that are too capital intensive when the rate of return exceeds the cost of capital have been documented by Averch and Johnson (1962), Baumol and Klevorick (1970) and others. Rate of return regulation has obvious allocative distortions that result from setting prices in approximate correspondence with average and not marginal costs,[2] and the "cost–plus" characteristic of rate of return regulation is generally inconsistent with efficient behavior under asymmetric information.[3] Joskow (1974) has questioned the accuracy of the rate of return regulation model as a description of actual regulatory practice. He noted that when utilities experienced rapid

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1 Written while Newbery was visiting from the University of Cambridge, England. We are indebted to Eddie Deckel, Joe Farrell and Drew Fudenberg for their helpful comments.

2 See Gilbert and Henly (forthcoming) for a discussion of the welfare costs of average cost pricing in electric power utilities.

3 The cost–plus characteristic of rate of return regulation emerges only as an extreme case in the incentive compatible contract design analyzed by Laffont and Tirole (1986). However Besanko (1985) identifies aspects of rate of return regulation in an incentive–compatible mechanism with imperfect information about the cost of capital.

improvements in productivity, regulators tended to set prices, not rates of return, and that rate of return regulation emerged only in response to adverse conditions of cost and demand.

Most of the theoretical literature on public utility regulation has studied regulation in a static context or in a finite game with asymmetric information.[4] Goldberg (1976) argued that this approach overlooks a critical feature of regulation, which is its role in defining the boundaries of conduct in a continuing relationship. This view, which is consistent with Williamson's (1976) persepectives on regulation in the cable TV industry and his criticism of the auction approach suggested by Demsetz (1968), informally characterizes regulation as a repeated game. It is well known that cooperative strategies that cannot be supported as equilibria when parties are concerned only with their immediate payoffs can be supported as equilibria in an infinitely repeated game.

This paper models a continuing regulatory relationship. The emphasis is on costs which are specific to the regulated firm, and therefore sunk after investment occurs. Sunk investments can be exploited by regulators whose concerns are dominated by consumer welfare in the short–run, but if such behavior were anticipated, the firm would be reluctant to invest in further capital, to the possible detriment of the regulator's constituency. In some circumstances this state of mutual fear can be sufficient to support an equilibrium in which both parties behave in a responsible manner.

In the years between 1940 and 1970, the electric power industry enjoyed declining costs of production and steadily increasing demand. In this stable environment, it is not difficult to envision how an implicit regulatory contract might have evolved that encouraged efficient behavior despite the clearly adverse incentives of rate of return regulation.[5] In the

[4] Averch and Johnson (1962), Baumol and Klevorick (1970) and Bailey (1973) are examples of the former. The latter include, among other contributions in a rapidly growing literature, Baron and Meyerson (1982), Sappington (1983), Guesnerie and Laffont (1984), Riordan (1984), Laffont and Tirole (1986), Sappington and Sibley (1986), Baron and Besanko (1987), and Spulber (1988).

[5] One characteristic of this efficient implicit contract may have been the suspension of rate of return regulation in favor of price regulation, as Joskow (1973) suggests. However, rate reviews in keeping with the principle of a fair rate of return on invested capital were not

1970s a combination of higher than expected costs and lower than expected demand upset the pattern of the post–war period, and many have argued that the traditional regulatory compact has fallen into disrepair. In order to capture how an implicit contract might function in a changing environent, we consider a market in which demand follows a Markovian process, with high demand more likely if demand was high in the recent past. The efficient level of utility investment is a function of the likelihood that demand is high or low. We find that in such an environment an institution such as rate of return regulation can be first best for the regulator. However, the changing pattern of demand can cause a system of rate of return regulation to be unsustainable as an implicit contract.

The equilibria that can be sustained in a continuing regulatory relationship depend on the consequences that would follow if parties acted in their short–term interests. These in turn depend on institutional constraints that define the actions which are permissible under the law. Our main objective in this paper is to study how insitutional constraints might affect the equilibria that are sustainable in a continuing regulatory relationship. We suppose that there is a third party, a "legislator", who specifies the permissible actions of the regulator before the game begins. The regulator may choose any compensation schedules that satisfy the constraints imposed by the legislator, and we suppose that the regulator will choose the actions that maximize its expected utility. To simplify matters, we assume that the regulated firm behaves as a Nash follower, with rational expectations as to the actions of the regulator.

Section II describes the structure of technology and demand in the model and characterizes efficient investment paths. Demand is stochastic and serially correlated. If current demand is high (a state we label "good" because it would ordinarily imply high investment), it is more likely to be followed by high demand in the next period than if current demand were low (a "bad" state). The utility must invest before demand is realized, knowing

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completely abandoned in this period, and, as we shall argue, rate of return regulation need not be inconsistent with efficient investment in a continuing relationship.

only demand in the previous period and the past behavior of the regulator. The regulator choses a compensation after the utility invests and demand is realized. If the game ended at that point, it would have a unique Nash equilibrium in which the regulator pays only marginal cost (expropriates all of the utility's sunk capital) and the utility does not invest.

Rate of return regulation loosely specifies that a utility is entitled to a fair return on its invested capital, provided that this capital was invested prudently and is employed in the public interest. In our model we interpret this institutional constraint as requiring a return at least as large as the cost of capital on all investment which is not idle. Following legal terminology that was applied to the regulatory treatment of excess capacity and cancelled plants, we refer to this rule of behavior on the part of the regulator as "used and useful" rate of return regulation (UUROR).[6]

We show in Section III that a policy of "used and useful" rate of return regulation can overcome the Averch–Johnson effect inherent in a regulatory policy that compensates the firm for its entire invested capital. There exist UUROR policies that encourage a price–taking utility to choose an efficient investment path with zero expected profit. Thus the recent behavior of regulators in disallowing expenditures on unnecessary plants or "imprudent" investments is not inconsistent with efficient regulatory behavior. The absence of such a policy would encourage either too much or too little investment.

Whether or not an efficient UUROR policy can be sustained depends on the "threats" that are permissible. Section IV considers two possible threat strategies. In the first game the regulator can and would revert to the Nash equilibrium of the one–shot game if the utility invested less than the capital required to meet baseload demand. We show that such a strategy is sufficient to sustain efficient behavior (with zero profits), with reasonable values for the cost

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[6] The $2.25 billion default of the Washington Public Power Supply System (WPPSS) could be construed as an example of the "used and useful" doctrine, although the legal wrinkle in WPPSS was that the member utilities were not held responsible to pay for electricity that was not delivered. Actual application of the used an useful doctrine has varied considerably in different regulatory jurisdictions. See Howe (1983) for a survey of regulatory treatment of cancelled plants.

of supply shortages. In addition, we show that a UUROR policy is efficient for the largest set of parameter values when the utility is allowed to earn strictly positive profits when demand is high, and is forced to earn strictly negative profits (on excess capacity) when demand is low. At the same time, the expected profits of the firm can be held to zero. This pattern of profitability is not inconsistent with the observed history of regulation, in which utility market values substantially exceeded their book values in the "golden years" from WWII until the mid–1960s, and then declined sharply until the mid–1980s.

A difficulty with the game described in Section IV is that the one–shot Nash strategy implies appropriation of sunk capital expenditures, which could be considered illegal under UUROR (although in equilibrium the utility would not invest and there would be no capital to appropriate). Thus in Section V we consider a variation of this game in which the regulator is never allowed to pay less than the cost of capital that is actually used. For reasonable parameter values, the equilibrium in this game has the utility investing only to produce base load demand. When UUROR is interpreted broadly to apply to all threatened behavior that may be feasible for the regulator, it becomes less likely that efficient investment behavior can be supported as an equilibrium.

In Section V we relax the judicial constraints imposed by the Legislator and suppose that the regulator can choose any compensation schedule in any of the four states, corresponding to demand in the current and preceding periods, but again subject to no expropriation of capital that is fully employed. We describe this alternative as price regulation. Price regulation includes UUROR as a special case, so it can be no worse and could be better. However, if the regulator is restricted to set only *linear* prices in each state, the regulator would have to transfer positive expected profits to the firm in any situation where the efficient investment path could be sustained as a SPNE under price regulation, but not under UUROR. Thus, with linear price regulation, any advantage over UUROR comes at the cost of transferring positive expected profits to the firm. In addition, if the regulator sets linear prices that depend only on the *current* state of demand, the firm must earn strictly positive profits in any efficient equilibrium. Rate of return regulation is equivalent to (nonlinear) price regulation in which prices depend on demand in both the current and the preceding period. When price regulation is restricted to policies that depend only on current realized demand, price regulation can be more expensive for a regulator than rate of return regulation because the utility must be compensated for the risk that it will have idle capital that does not earn revenues.

II The Model

In each period t the utility chooses a non–negative level of investment, k_t, to bring total capital in the next period up to the desired level, K_{t+1}. The period is sufficiently long that capital completely depreciates if there is no new investment, so that $K_{t+1} = k_t$. At the time of the investment decision, demand in period t+1, D_{t+1}, is not known, but may take either of two levels (both independent of price over the relevant range), Q or Q(1–σ). (The inelasticity of demand simplifies the analysis, but suppresses questions of allocative efficiency). Demand follows a Markovian process, with demand more likely to be high this period if it was high last period. Specifically:

$$(1) \qquad \Pr(D_{t+1} = Q) = \begin{cases} 1 - \theta P & \text{if } D_t = Q, \quad \theta < 1, \\ 1 - P & \text{if } D_t = Q(1-\sigma). \end{cases}$$

Equivalently, there are four possible states of the world described by demand in the current and previous period. Good states (so labelled because they are good for investment and will normally be associated with high levels of capacity) are those that experienced high demand last period (and are thus more likely to have high demand this period), whilst bad states are those which had low demand last period. Each of these states may experience high or low current demand, so the set of states may be labelled (GH,GL;BH,BL).

The capacity (in terms of potential supply) of capital K is K/v, the variable operating cost is b/unit (constant), and there is an alternative source of supply available at a constant total unit cost c/unit, where $c > b + rv$, and where r is the gross rate of interest (including depreciation). The technology thus exhibits fixed coefficients, which means that the concept of excess capacity is well–defined.

The utility must choose investment each period not knowing future demand with certainty, nor the revenues that it will be allowed to earn next period. The sequence of moves for the utility and the regulator is shown in Figure 1. The choice of investment in period t determines the capital stock in period t+1 and occurs before demand is realized in t+1. The regulator chooses a transfer of revenues to the utility, R_{t+1}, which is determined with full information about both K_{t+1} and D_{t+1}. Figure 1 defines a "basic game" which repeats in every period $t = 0, 1, ..., \infty$.

We assume the regulator is concerned only with consumer surplus. This assumption emphasizes the opportunity of the regulator to engage in strategic behavior with respect to sunk investments – there would be no problem if the regulator were indifferent as to the distribution of income between consumers and the utility (or its shareholders), nor if the regulator were acting primarily in the interest of the utility.[7] In that case, conditional on the choice of investment, the "one–shot" game is zero–sum and has a unique Nash equilibrium in which the regulator sets price equal to variable cost and the utility does not invest.

It is well known that the infinitely repeated game can support an infinity of Subgame Perfect Nash Equilibria (SPNE) that are Pareto–preferred to the Nash equilibrium of the one–shot game. Our interest is investigating how institutional constraints that limit the strategy choices which are available to the regulator might restrict the set of SNPE. Formally, we suppose the game includes a "legislator", who at t = 0 specifies the set of strategies that are legally permissible for the regulator.

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[7] Our characterization is an extreme form of a political orientation which appears to describe recent regulatory objectives in some jurisdictions in the United States. The regulator is thus "captured" in the sense described by Stigler (1971) and Peltzman (1976), but the capture is by consumers, not producers.

Before comparing alternative regulatory regimes as defined by permissible strategy sets, consider as a benchmark the cost–minimizing investment path. Suppose that efficient investment has $K = vQ$ in good states and $K = vQ(1-\sigma)$ in bad. For this to be efficient, the net cost of supply must be minimized at these levels. In good states (superscripted g) the expected cost is

$$C^g = \underset{K}{\mathrm{Min}}\Big\{(1-\theta P)[b\mathrm{Min}\{Q,K/v\} + c\mathrm{Max}\{Q-K/v,0\}] + \theta P[b\mathrm{Min}\{Q(1-\sigma),K/v\} + c\mathrm{Max}\{Q(1-\sigma)-K/v,0\}] - rK\Big\},$$

and for the optimum choice of K to be vQ:

$$(1-\theta P)(c-b) > rv. \tag{2}$$

Likewise, in bad states (superscripted b) the expected cost is

$$C^b = \underset{K}{\mathrm{Min}}\Big\{(1-P)[b\mathrm{Min}\{Q,K/v\} + c\mathrm{Max}\{Q-K/v,0\}] + P[b\mathrm{Min}\{Q(1-\sigma), K/v\} + c\mathrm{Max}\{Q(1-\sigma)-K/v,0\}] - rK\Big\},$$

and for $K = vQ(1-\sigma)$:

$$rv > (1-P)(c-b). \tag{3}$$

For future reference it might be useful to think of values for the cost parameters, c, b and rv. The value of alternative sources of supply, c, will depend on whether small amounts are needed, in which case purchasing power from nearby utilities may be feasible at a typical figure in 1988 of c = 9 cents/KWhr, or whether substantial shortfalls must be made up, in which case the shortage costs, c, may be very high indeed. Typical values for the costs incurred by the utility might be b = 2 cents/KWhr, rv = 5 cents/KWhr for nuclear, and b = 4 cents and rv = 3 cents for coal. Thus for nuclear (taking the lower value of c), $K = vQ(1-\sigma)$ in bad states and vQ in good states requires $(1-\theta P) > 5/7 > (1-P)$, whilst for coal $(1-\theta P) > 3/5 > (1-P)$. Both will be satisfied for $\theta = P = 1/2$.

III Alternative Regulatory Regimes

Strictly interpreted, rate of return regulation implies that the regulator must transfer sufficient revenues in each state to ensure that the utility earns at least a normal rate of return on its invested capital. This policy leads to the over–capitalization problem described in Averch and Johnson (1962), Baumol and Klevorick (1970), and others. Strict rate of return regulation is not mandated by legal precedent. In its most decisive opinion on the scope of utility regulation (*FPC v. Hope Natural Gas*), the U.S. Supreme Court concluded that "rates which are adequate to attract capital for growth ... are not unreasonable", but the Court did not say that the regulators are obligated to provide at least a normal rate of return at all times. Rates that persistently fail to compensate firms for their invested capital could run foul of the due process protection of the Constitution (as expressed, for example, in *Smythe v. Ames*, 1898). This difficulty does not arise here because we impose the individual rationality condition that in a SPNE the value of the firm must be non–negative, otherwise the utility would choose to abandon its franchise.

In the postwar history of utility regulation in the United States, utilities frequently earned rates of return that exceeded their capital costs (see Joskow, 1974).[8] However, in recent years, regulators have disallowed compensation for investments that were considered to be either "not used or useful" or "imprudent". Typically, the first case has involved

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[8] Greenwald (1984) discusses the view that a fair rate of return might be one which equated the market to book value of the stock. In the 1960s the ratio of the market to book value was greater than 2.

expenditures on discontinued or unnecessary plants and the second expenditures on nuclear plants that have experienced large cost overruns. In either case, the net effect is to reduce actual earned rates of return below a normal return on investment in special circumstances.

In this model, the restriction on strategies is formally interpreted to require at least a normal return on capital except in circumstances in which there is excess capacity. The consequences of this restriction are explored below.

III.1 "Used and Useful" Rate of Return Regulation

We define used and useful rate of return regulation (UUROR) as requiring the regulator to pay at least a normal return on invested capital up to an amount equal, in our model, to realized demand, but the regulator has the latitude to offer rates that fail to compensate the utility for investment when there is excess capacity. Suppose that the regulator pays a gross return r on invested capital up to $vQ(1-\sigma)$, and thereafter $s(i)$ in the demand state $i = \{H,L\}$ on the additional capital, up to a maximum of vQ. This policy is described by the revenue function

$$R(i, K_t, Q_t) = bQ_t + r.\mathrm{Min}\{K_t, vQ(1-\sigma)\} + s(i).\mathrm{Min}\{vQ, \mathrm{Max}[K_t - vQ(1-\sigma), 0]\}.$$

Let $s(H) = s$ and $s(L) = s'$. A policy with $s \geq r$ and $s' \leq r$ is permissible under UUROR. The expected profit to the utility in good states is

$$\pi^g = \Big\{(1-\theta P)s + \theta Ps' - r\Big\}\{K - vQ(1-\sigma)\}, \quad vQ(1-\sigma) \leq K \leq vQ, \tag{4}$$

and to induce the utility to set $K = vQ$, $\{(1-\theta P)s + \theta Ps' - r\} \geq 0$. Expected profit in bad states is

$$\pi^b = \Big\{(1-P)s + Ps' - r\Big\}\{K - vQ(1-\sigma)\}, \quad vQ(1-\sigma) \leq K \leq vQ, \tag{5}$$

and to induce the utility to install $K = vQ(1-\sigma)$, $\{(1-P)s + Ps' - r\} < 0$. Let $s = r + \rho$ and $s' = r - \mu$, with $\rho, \mu > 0$ to satisfy the efficiency constraints. The cost minimizing choice of ρ, μ is to set $\pi^g = 0$, or

$$(6) \qquad \rho = \theta P\mu/(1-\theta P).$$

Provided $\rho, \mu > 0$, $\pi^b = 0$ as $K^b = vQ(1-\sigma)$, so the utility will earn zero expected profits in both states.

The next step is to check that the regulator would not wish to have $K = vQ$ in all states, which it could achieve by setting $(s, s') = (r+\varepsilon, r+\varepsilon)$, ($\varepsilon$ small), nor $K = vQ(1-\sigma)$ in all states, which it could achieve by setting $(s, s') = (r, r-\varepsilon)$. It can readily be established that for neither of these to be preferable

$$(7) \qquad 1-\theta P > \frac{rv}{c-b} > 1-P,$$

which is the same condition as (2) and (3). Thus the socially efficient pattern of investment would be chosen provided the regulator can commit to this policy.

Because the policy $R(\cdot)$ induces efficient investment behavior and, for values of ρ, μ satisfying (6), extracts all the consumer surplus, it is a first best policy for the regulator, again, provided that the regulator can commit herself to this policy. The desirability of this policy is summarized in

Proposition 1. A commitment to the cost–minimizing rate of return policy $R(\cdot)$ is a first–best policy for the regulator.

The only difficulty that $R(\cdot)$ might pose for the regulator is that there need not exist an (s, s') policy which supports the efficient investment plan as a SPNE of the repeated game. To investigate this question, we need a more formal specification of the repeated game without commitment.

IV The sustainability of regulation

If the regulator cannot be bound to her announced policy (of setting an agreed rate of return or price), after the utility has invested, then we need to inquire whether the regulator will ever have an incentive to deviate from her stated policy and whether she can credibly commit to not deviating.[9] We can model this problem as a game played between the regulator and the utility. In each period the regulator can either continue with the policy, or she can deviate. After observing the regulator's choice, the utility can then either continue investing as though the regulator were committed to continue her policy into the future, or, if the regulator has deviated, it can adopt a different investment plan. We can then investigate the set of perfect Nash equilibria in this repeated game.

Formally, the game can be described in much the same way as the model of collusion under uncertainty in Green and Porter (1984). The regulation game is an infinite repetition of a "basic game", the moves of which are summarized in Figure 1. The information when the utility invests is realized demand in period t–1, which signals whether the state is good or bad. In addition, the utility looks ahead to the return it can anticipate on its invested capital. After demand is realized in period t, the regulator chooses a revenue transfer function $R_t(\cdot)$, conditional on the realized demand, and the utility then chooses output, $Q_t \leq \min\{K_t/v, D_t\}$. The payoff to the utility at the termination of the basic game is $\pi_t = R_t - bQ_t - rK_t$, and the payoff to the regulator (relative to the alternative of purchasing Q_t at a cost, c) is

[9] The issue of credibility has been discussed by Kydland and Prescott (1977) in the macroeconomic context, and by Roberts (1983), who looks at limitations on the taxation of capital (though in a setting of asymmetric information, in contrast to our model).

$U_t = cQ_t - R_t$ (provided the regulator acts within the constraints imposed by the legislator). Both the utility and the regulator are risk neutral.

The unique Nash equilibrium of the basic game is $\{R, K\} = \{bQ_t, 0\}$. The regulator will price at variable cost, b, and the utility does not invest (and therefore $Q_t = 0$). Any investment would be expropriated by the regulator, who will price at variable cost in order to utilize available capacity. Given this behavior by the regulator, there is no reason for the utility to invest.

The regulation game is an infinite repetition of the basic game. The regulator chooses a revenue function $\{R_t(\cdot)\}$ to maximize $E[\Sigma_{t=0}^{t=\infty} \beta^t U_t(R_t,Q_t)]$, where β is the discount factor. The utility chooses $\{Q_t, K_{t+1}\}$ to maximize $E[\Sigma_{t=0}^{t=\infty} \beta^t \pi_t(R_t,Q_t,K_t)]$, subject to $Q_t \leq \min\{K_t/v, D_t\}$. The regulator and utility have complete information on the history of demand and actions by each party. Note that as a consequence of the sequential nature of the basic game, the information available to each party in period t is different. The regulator knows K_t and D_t, while the utility knows only D_{t-1} before it chooses K_t, and it knows both D_t and $R_t(\cdot)$ when it chooses Q_t.

A *contingent strategy* for the regulator is an infinite sequence $S^r = \{S_0^r, S_1^r, .., S_t^r, ..\}$, where S_t^r determines a revenue function as a function of history, $S_t^r(h_t^r) = R_t(\cdot)$. Similarly, a contingent strategy for the utility is an infinite sequence $S^u = \{S_0^u, S_1^u, .., S_t^u, ..\}$, where K_0 is given, and S_t^u determines output and next period's capital as a function of the history, h_t^u, available to the utility: $S_t^u(h_t^u) = (Q_t, K_{t+1})$.

A strategy profile is defined as the pair of contingent strategies $\{S^r, S^u\}$, and expectations are taken with respect to the probability distribution of prices and outputs this induces. A Nash equilibrium is then a strategy profile $\{S^{r*}, S^{u*}\}$ which satisfies

$$E_{S^{r*}, S^u}[\Sigma_{t=0}^{t=\infty} \beta^t \pi_t\{S_t^u(h_t^u), S_t^{r*}(h_t^r)\}] \leq E_{S^{r*}, S^{u*}}[\Sigma_{t=0}^{t=\infty} \beta^t \pi_t\{S_t^{u*}(h_t^u), S_t^{r*}(h_t^r)\}],$$

and

$$\underset{S^r, S^{u*}}{E}[\Sigma_{t=0}^{t=\infty} \beta^t U_t\{S_t^{u*}(h_t^u), S_t^r(h_t^r)\}] \leq \underset{S^{r*}, S^{u*}}{E}[\Sigma_{t=0}^{t=\infty} \beta^t U_t\{S_t^{u*}(h_t^u), S_t^{r*}(h_t^r)\}],$$

for all feasible strategies S^r, S^u. In all cases we assume that the utility acts as a Nash follower taking the actions of the regulator as given.

We confine our investigation of equilibrium strategies to those that are subgame perfect. Equilibria will differ according to the the legislative constraints which restrict the regulator's choice of revenue transfers, and the feasible responses to deviations by the participants. In game 1 below, we assume that if the regulator does not follow a UUROR revenue function, then the game will degenerate into the one–shot Prisoner's Dilemma. Because the utility acts as a Nash follower, the only rational deviation by the regulator is complete expropriation of the sunk capital. This action could be interpreted as not legally permissible under the rules of UUROR. Therefore in game 2 we modify game 1 to remove the expropriation option.

We can now inquire whether rate of return regulation is sustainable for the case in which the efficient equilibrium requires variations in capacity – that is, equations (2) and (3) are satisfied. The game is specified as

Game 1 Rate of Return Regulation

Rate of return regulation is defined by the revenue function, defined as:

(8) $$R(i, K_t, Q_t) = bQ_t + r.\mathrm{Min}\{K_t, vQ(1-\sigma)\} + s(i).\mathrm{Min}\{vQ, \mathrm{Max}[K_t - vQ(1-\sigma), 0]\}.$$

As before, the regulator promises to pay a gross return r on capital installed up to $vQ(1-\sigma)$, and thereafter $s(H) = s = r + \rho$, $s(L) = s' = r - \mu$ on capital up to a maximum of vQ. The values of ρ, μ are chosen to satisfy (6), and are thus cost minimizing. The regulator's strategy is $S_t^r(h_t^r) = R_t$:

$$R_0 = R(i_0,K_0,D_0),$$

$$(9) \quad R_t = R(i_t,K_t,D_t), \qquad \text{if } K_t \geq vQ(1-\sigma) \text{ and } R_{t-1} \geq R(i_{t-1},K_{t-1},D_{t-1}),\ t > 0,$$

$$(10) \quad = bQ_t, \qquad \text{otherwise.}$$

The utility's strategy is the choice of capital and output that maximizes its present discounted profit, taking S_t^r as given. Of course, the utility will only invest if the expected present discounted value of the franchise, V^u or W^u, is non–negative.

We can now examine the perfect equilibria of this game. The one–shot "Prisoner's Dilemma" outcome $\{bQ_t; 0\}$ is clearly an equilibrium, for if $R_t = bQ_t$, $K_{t+1} = 0$, and then by (10), $R_{t+1} = bQ_{t+1}$ and so on. The next question is whether the efficient solution $\{(r; s, s'); (vQ, vQ(1-\sigma)\}$ is also an equilibrium (adopting the natural shorthand that the first bracket characterises the form of regulation, the second the level of capital in the two states). This in turn involves checking that the regulator would not wish to deviate from (9), given that it would lead to a SPNE with zero investment next period.

The advantage to the regulator of deviating is the value of the current capital stock, the return on which is effectively expropriated. The disadvantage is the cost of having to meet future demands from other sources, or the cost of any shortages which might result. In the present framework the regulator may wish to deviate in state GH or GL, depending on the size of ρ, μ. This case is analyzed in the Appendix. The simpler case to examine is when the utility underinvests, so that $K_t = K \leq vQ(1-\sigma)$, which is a possible equilibrium of the game. (If $\sigma \to 0$, this is equivalent to the case analyzed in the Appendix). Suppose that the period under question is sufficiently long that capital completely depreciates if there is no new investment.

(The continuous time case is dealt with in the next footnote and yields essentially the same results). The value to the regulator of paying the rate of return on the full capacity, rather than having no capacity, is

(11) $$U^r = (c-b-rv)K/v$$

per period. The present value of this stream of benefits is $V^r = U^r/(1-\beta)$. The advantage of deviating is the one period capital cost saving, rK, and the cost is βV^r from losing the benefits of capital from next period. Deviating is unattractive if

$$rK < \beta V^r = \frac{\beta}{1-\beta}(c-b-rv)K/v,$$

or

(12) $$\xi \equiv \frac{c-b}{rv} > \frac{1}{\beta}.$$

If this condition is satisfied, the regulator will have no incentive to expropriate the utility's capital stock when the utility maintains a constant level of capacity, regardless of its level.[10] If

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10 In continuous time the problem can be set up as follows. Let $dK/dt = I - \delta K$, where I is gross investment, and δ is the rate of depreciation. If demand grows at rate g, and the rate of interest is i (so that $r = i + \delta$ is the gross rate of return), the present discounted cost of supplying electricity under rate of return regulation is

$$\int_0^\infty (b+rv)Q_0 e^{gt} e^{-it} dt = (b+rv)Q_0/(i-g).$$

If the regulator deviates the utility supplies $Q_0 e^{-dt}$ at date t,the balance being met at shortage cost c. The present discounted cost is

$$Q_0 \int_0^\infty \{be^{-dt} + (e^{gt} - e^{-dt})c\} e^{-it} dt = Q_0\{c/(i-g) - (b-c)/(i+\delta)\}.$$

Deviating is unattractive if the second cost exceeds the first; that is, if

$$\frac{c-b}{rv} > \frac{i+\delta}{\delta+g} = \frac{r}{\delta+g}.$$

the utility increases capital to vQ in good states, the regulator will be tempted to expropriate unless $\xi > \xi^*$, where the derivation of ξ^* is discussed in the Appendix.

There are two possibilities. If $\xi > \xi^*$, the regulator will have no incentive to expropriate the utility's capital stock in any state, and the efficient equilibrium $\{(r; s, s'); (vQ, vQ(1-\sigma)\}$ will be sustainable as a SPNE. If $\xi^* > \xi > 1/\beta$, the regulator would expropriate if $K = vQ$, but would not expropriate if $K \leq K^* < vQ(1-\sigma)$. The utility, knowing this, will set $K_H = K^*$, and the equilibrium will be $\{(r; s, s'), (K^*, vQ(1-\sigma)\}$, which is inefficient.

If $P = 0.85$, $\theta = 0.5$, $\sigma = 0.2$, $\beta = 0.2$, $rv = 5$, $b = 2$ cents/KWhr, then $\xi^* = 5.76$, and $\xi > \xi^*$ if $c > 31$cents/KWHr. This is not an unreasonably high figure for the cost of failing to have reliable power supplies, which is likely to be very large indeed. Another way of looking at the condition is that if $c = 31$cents/KWhr, then $\beta > 0.2$. This condition may be interpreted in terms of the length of the period over which the capital stock depreciates. Thus, if the rate of discount is 9 per cent real, the length of the time period corresponding to $\beta = 0.2$ is 18.6 years. (Properly speaking, this period should be compared with the half–life of the capital stock, and as such is high). Higher shortage costs, c, will make deviations less attractive.

V Trigger strategies for small deviations

As we remarked earlier, the rules of UUROR are likely to make it illegal to expropriate the entire capital stock, though they do not restrict the regulator from paying a low, possibly zero, return on excess capacity. Instead of expropriating the whole capital, therefore, the regulator is effectively limited to expropriating surplus capital. Knowing this, the utility's best response to such a minor deviation is to avoid any excess capacity by underinvesting. Of course, if the utility does not satisfy the conditions of the franchise and supply at least base load capacity, then the regulator is no longer bound by the rules of UUROR, and may

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The worst case is when $g = 0$, and if $r = 12\%$, $\delta = 3\%$, then the condition is $(c-b)/rv > 4$, similar to the condition in the text, and guaranteed by $c > 22$ cents.

expropriate in such cases.

Formally, we can set this up as the following

Game 2 Threat-constrained rate of return regulation

The game is essentially the same as game 1 except that the regulator cannot expropriate except in response to a failure to supply base load capacity. Rate of return regulation is defined by the same revenue function as in game 1, equation (8) with $s(H) = s = r + \rho$, $s(L) = s' = r - \mu$, and ρ, μ satisfying (6). The game is "threat–constrained" in the following respect. If the utility fails to provide the efficient level of capacity when demand is high, but invests enough to meet base load demand, the regulator will pay a price $p_t = b+rv$ in the next period (i.e. will set $s' = 0$ and pay no return on unutilized capacity). This will be sufficient for the utility to break even on its installed capacity. If the utility fails to meet base load, the regulator will pay b and the market will collapse to the one–shot Prisoner's Dilemma equilibrium of the basic game. Thus the regulator tolerates underinvestment which meets base load, but reverts to the myopic strategy if the utility fails to perform to this minimum level.

The regulator's strategy is $S_t^r(h_t^r) = R_t$:

$$R_0 = R(i_0, K_0, H)$$

$$\begin{aligned}
R_t &= R(i_t, K_t, D_t) && \text{if } K_t \geq vD_{t-1} \text{ and} \\
&&& \quad R_{t-1} \geq R(i_{t-1}, K_{t-1}, D_{t-1}),\ t > 0, \\
&= (b+rv)Q_t && \text{if } vQ(1-\sigma) \leq K_t < vD_{t-1},\ t > 0, \\
&&& \text{or } (b+rv)Q_\tau \leq R_\tau < R(i_\tau, K_\tau, D_t) \text{ for some } \tau,\ 0 \leq \tau < t, \\
&= bQ_t && \text{if } K_t < vQ(1-\sigma).
\end{aligned}$$

Now consider what would happen if the regulator reduced the revenue in state GL from $(b+rv)Q(1-\sigma) + \sigma s'vQ$ to $(b+rv)Q(1-\sigma)$. Given these strategies the utility would predict that all future prices would be either b or b+rv. At prices b+rv it would be unattractive to increase capacity above $vQ(1-\sigma)$ in good states, and it would be attractive to continue investing at least $vQ(1-\sigma)$ at this predicted price. Thus b+rv is a rational forecast if the utility invests $vQ(1-\sigma)$.

The regulator can deviate from $R(\cdot)$ by moving to $(b+rv)Q_t$. (It would not be rational to choose any other compensation if the regulator deviates from R(.)). If she sets price at $p^* = b+rv$ in state GL the one–period gain is $(r-\mu)vQ\sigma$, and the loss is the expected present value of having capacity $vQ(1-\sigma)$ at price p^* rather than $\{(r,s,s'); (vQ(1-\sigma),vQ)\}$. The expected gain to the regulator of having rate of return regulation in good states rather than $vQ(1-\sigma)$ at $p^* = b+rv$ is

$$U^g/Q = (1-\theta P)\{c-b-sv)\sigma - \theta P\sigma s'v = \{(1-\theta P)(c-b) - rv\}\sigma, \tag{14}$$

whilst the gain in bad states is zero. The present value of the (r; s, s') regime to the regulator starting in a bad state is therefore

$$W^r = \frac{\beta(1-P)U^g}{(1-\beta)\{1-\beta P(1-\theta)\}}, \tag{15}$$

(where the algebra is presented in the Appendix). The one period gain from deviating will be unattractive if

$$(r-\mu)vQ\sigma < \beta W^r. \tag{16}$$

Next, consider the consequences of reducing the revenue in state GH from $(b+rv)Q + \sigma\rho vQ$ to $(b+rv)Q$ – i.e. not paying the premium on capital of ρ which was designed to compensate for the shortfall of μ in the rate of return in low demand states. The utility will respond to this minor deviation by setting $K = vQ(1-\sigma)$. The one period gain from the deviation is $\sigma\rho vQ$, and the cost is βV^r (where V^r is the value to the regulator of continuing with efficient investment under $R(\cdot)$, rather than moving to the underinvestment equilibrium, starting from a good state). The deviation will be deterred if

(17) $$\sigma\rho vQ < \beta V^r.$$

The regulator must now choose the level of ρ (or μ) to satisfy constraints (16) and (17), if possible. Deviation in state GL can be made less likely by increasing μ, but, by (6) this requires that ρ be increased, and thus increases the likelihood that deviation in state GH will become attractive. The borderline case will occur when the only credible UUROR which supports the efficient investment plan increases ρ, μ to the point where the incentive to deviate is equal in states GH, GL:

(18) $$\frac{r-\mu}{W^r} = \frac{\rho}{V^r},$$

which, from the formulas given in the Appendix, can be written

$$\beta(1-P)\rho = (1-\beta P)(r-\mu).$$

Together with the cost–minimizing relationship between ρ and μ given in (6), this can be solved to give

(19) $$\mu = \frac{r(1-\beta P)(1-\theta P)}{1-P(\theta+\beta-\theta\beta)};\quad \rho = \frac{(1-\beta P)\theta P r}{1-P(\theta+\beta-\theta\beta)}.$$

If ρ, μ are set at these levels, deviations will be deterred provided (16) (or, equivalently, (17)) is just satisfied, i.e. provided ξ exceeds some critical value $\hat{\xi}$, say.

The various possible equilibria of the game can now be described. If $\xi \geq \hat{\xi}$, then the outcome will be the efficient equilibrium $\{(r; s, s'); (vQ, vQ(1-\sigma)\}$. If $\hat{\xi} > \xi \geq 1/\beta$, the utility will set $K = K^* < vQ(1-\sigma)$, and the outcome will be the underinvestment equilibrium $\{(r; s, s'); (K^*, vQ(1-\sigma)\}$. Finally, if $\xi \leq 1/\beta$, then the best the regulator can do is set $p = p^* = b+rv$, so $\{b+rv; vQ(1-\sigma)\}$ is a perfect equilibrium. Summarizing:

Proposition 2 Under "used and useful" rate of return regulation, it may be desirable to pay a below normal rate of return on excess capacity, which will be compensated by above normal rates of return at other times, in order to sustain the efficient pattern of investment. Even then, it may not be possible to sustain the efficient equilibrium and the utility may underinvest.

It is worth stressing that the flexibility provided by the "used and useful" doctrine has advantages and drawbacks. On the one hand the ability to reduce s' and raise s allows the regulator to transfer profits between states GL, GH, and thus to reduce the incentive to deviate (by either setting $s' = 0$ or $\rho = 0$). This may be sufficient to deter such deviations, and thus allow the efficient equilibrium to be sustained. On the other hand the freedom to pay less than the normal return in low demand states provides the regulator with the opportunity to exploit the utility. Whether the advantage outweighs the disadvantage turns on the response of the utility to small deviations, and the likelihood that the players will make costly errors, neither of which is adequately modelled in our stylized game.

VI Price Regulation

The main conclusion of rate of return regulation was that it is efficient, provided that it is sustainable, but that it might not be sustainable within the legislative framework we examined. This raise the question as to whether there is an alternative form of regulation which may be superior to UUROR. Britain, with its very different institutional history and regulatory legislation, has recently privatized a number of previously nationalised utilities – gas, telecoms – and is about to privatize the electric supply industry. In each case the legislated method of regulation has been to limit the price that the utility can charge on its regulated sales, not to set the rate of return. Typically, the utility is constrained from setting a price higher than a figure determined by an annually adjusted index formula. This formula may include fuel costs, the consumer price index, or other observable price indices, but usually excludes cost data from the regulated utility. The advantages of this approach are clear – the price ceiling provides incentives for cost minimization and rewards improvements in efficiency in a way absent from cost–based methods of regulation. Our model does not address these incentive issues, but we can ask whether these advantages come at a cost in terms of the issues we do discuss. Can price regulation do as well as rate of return regulation by the standards we discuss – efficiency, measured by the choice of investment, cost to consumers, and sustainability?

Price regulation can take almost any form, but there are a number of specifications that seem natural in the present setting. The distinctive feature of price regulation is that the utility receives no return on unutilized capacity, though this may not be as significant a difference as might at first appear. If we initially restrict attention to *linear* price schedules, then it is natural to consider specifying four state–specific prices, p_i, $i \in \{GH,GL;BH,BL\}$. In good states the utility will earn expected profits

(23) $$\pi^g = (1-\theta P)(p_{GH}-b)K/v + \theta P(p_{GL}-b)\mathrm{Min}\left\{Q(1-\sigma),\, K/v\right\} - rK, \quad K \le vQ,$$

and the condition for choosing $K = vQ$ is

(24) $$p_{GH} \geq b + rv/(1-\theta P).$$

The regulator will ensure this is satisfied with equality, and can set $p_{GL} = b$, at which level expected profits, π^g, are held to zero. In the bad state the utility will earn expected profits

$$(25) \qquad \pi^b = (1-P)(p_{BH}-b)K/v + P(p_{BL}-b)\text{Min}\left\{Q(1-\sigma), K/v\right\} - rK, \;\; K \geq vQ(1-\sigma).$$

There are a wide range of prices satisfying the condition that the utility will choose $K = vQ(1-\sigma)$ and make non–negative profits[11] — provided $p_{BH} < b+rv/(1-P)$. The natural choice is $p_{BL} = p_{BH} = b+rv$, which again minimizes the expected consumer cost by holding profits to zero.

The ex–post realized profits will be

$$\pi_{GH} = \frac{rvQ\theta P}{1-\theta P}; \quad \pi_{GL} = -rvQ,$$

and zero in the other two states. (The convention on notation here is that π^g is the expected profit in good states, π_{GH} is the realized profit in state GH). Compared to rate of return regulation, this form of price regulation has the same expected cost but greater variability from period to period unless $\rho > r\theta P/\{\sigma(1-\theta P)\}$.

If the regulator were to choose a single price high enough to induce the efficient level of investment, then the price would have to be $b+rv/(1-\theta P)$, and the utility would now make expected profits in good and bad states, at the expense of the consumers. If the regulator were to choose prices contingent only on current demand (high or low), then again a price $p_H = b+rv/(1-\theta P)$ is required to induce efficient investment. This will insure that the utility makes positive expected profits in good states, and, as a result, the price in low demand states, p_L,

[11] If the utility is to be held down to zero expected profits in good states, it must be ensured non–negative expected profits in bad states if the present value of holding the franchise is to be non–negative.

can be held below average cost, b+rv, resulting in expected losses in bad states. The only constraint is that the present value of profits, starting from either good or bad states, be non–negative. If $\pi^g > 0 > \pi^b$, then the formulas in the Appendix show that $V^r > W^r$, so the binding constraint will be $W^r = 0$, and the utility will make strictly positive expected profits in good states, at the cost of higher prices for consumers than rate of return regulation.

If the regulator can specify a non–linear price schedule, the two–part tariff described by the revenue function

$$(26) \qquad R(q_t) = bQ_t + rv.\mathrm{Min}\{Q_t, vQ(1-\sigma)\} + \frac{rv}{1-\theta P}.\mathrm{Max}\{0, Q_t - vQ(1-\sigma)\}$$

is the natural analog of the UUROR (r,s,s').

This pays b+rv on the first $vQ(1-\sigma)$ units, and $b+rv/(1-\theta P)$ on additional sales, and will induce the efficient level of investment. Like the four–state price rule, it yields zero expected profit in good and bad states. The ex–post realized profits will be

$$\pi_{GH} = \frac{\sigma rvQ\theta P}{1-\theta P}; \quad \pi_{GL} = -\sigma rvQ,$$

and zero in the other two states. The variability of profits will thus be lower (only σ times the size) of those in the four–state system of price regulation.

Thus if prices are either non–linear or state–contingent, they can induce efficient investment at least cost to consumers as effectively as rate of return regulation. The remaining question is whether there is a system of price regulation which is as good as or better than rate of return regulation as far as sustainability is concerned. The major problem with sustaining the efficient outcome is that the short–term benefits of deviating may be too great. The temptations to deviate are higher, the more profits of the utility can be appropriated by the regulator. Under UUROR, we saw that the temptation to deviate could be minimized by raising ρ, μ, and thus reducing utility profits in GH whilst reducing losses in GL, until the incentives to deviate were equalized in both states. Under price regulation, if the regulator can make state–contingent transfers T_i in state i, then it would be possible to exactly replicate UUROR. In fact, it is also possible to do better than UUROR, because there are now four instruments, T_i, rather than two, ρ and μ. If all four transfers are non–zero, though, the cost to consumers will be higher than under UUROR. Consider the set of transfers:

(27) $$T_{GH} = -A - \theta PB; \quad T_{GL} = -A - (1-\theta P)B;$$

$$T_{BH} = C - DP; \quad T_{BL} = C + (1-P)D,$$

where A, B, C ≥ 0. The expected profits are now $\pi^g = -A$, $\pi^b = C$, and for the utility to wish to continue investing, the present discounted value of profits, V^u, $W^u \geq 0$. If A > 0, then $V^u = 0$ implies $W^u \geq 0$, and for $V^u = 0$,

$$A = \frac{\beta\theta PC}{1-\beta P}.$$

Then A, B, and D can be chosen to make the gains from minor deviations equal in each of the four states, rather than just equating them in two states, as with UUROR. These two conditions, together with two boundary conditions at which the incentives to deviate are exactly balanced by the costs (the four state counterparts to (16) and (17) holding with equality) give four equations in A, B, D, and $\xi \equiv (c-b)/rv$. Since A, B, and D > 0, the condition on ξ is strictly weaker than under UUROR. Formally, we can model unconstrained price regulation as

Game 3 Threat-constrained non–linear price regulation

Price regulation is defined by the revenue function given in (26) and by state–contingent transfers $T_t = T(i_t)$ defined by (27). We continue to suppose that as in Game

2 the regulator cannot expropriate the utility except in response to failing to supply base load. The regulator's strategy is $S_t^r(h_t^r) = R_t + T_t$:

$$S_0^r = R(Q_0) + T_0,$$

$$S_t^r = R(Q_t) + T_t \qquad \text{if } K_t \geq vD_{t-1}, \text{ and } R_{t-1} \geq R(Q_{t-1}),\ t \geq 0$$

$$= (b+rv)Q_t \qquad \text{if } vQ(1-\sigma) \leq K_t < vD_{t-1},\ t > 0,$$
$$\text{or } (b+rv)Q_\tau \leq R_\tau < R(Q_\tau) \text{ for some } \tau,\ 0 \leq \tau < t,$$

$$= bQ_t \qquad \text{if } K_t < vQ(1-\sigma).$$

It will be seen that if $A = C = D = 0$, and $B = s'vQ\sigma/(1-\theta P)$, then the transfers to the utiliity are identical to those of Game 2, and in this case Game 3 will have the same equilibria. As argued above, A, C, and D can be increased above zero, thereby increasing the range of values of ξ that are sustainable as efficient SPNE. However, if $A > 0$, the present discounted value of utility profits in bad states, W^u will be strictly positive, implying that the present discounted cost of electricity will be higher than under UUROR. This extra cost is the price that must be paid to sustain the efficient equilibrium, rather than accepting the underinvestment equilibrium. Summarizing

Proposition 3. Provided the regulator can make state–contingent transfers to the utility, non–linear price regulation can replicate the efficiency and sustainability properties of rate of return regulation, and can also sustain efficient equilibria which could not be sustained under rate of return regulation, though at a higher cost to the consumer.

It should be clear that the state contingent transfers are necessary, not only to improve upon UUROR, but even just to achieve the same degree of sustainability. Whereas such transfers are very natural (and indeed are the essence of) UUROR, they are far from natural in the context of price regulation. Because rate of return regulation pays a (possibly state–contingent) return on the total capital, it has a natural base on which to make the required state–contingent transfers. Price regulation specifically excludes payment on unutilized capacity, and thus lacks a natural mechanism for making these transfers. Thus, whilst in our model it is possible to improve upon "used and useful" rate of return regulation, it is not clear how well such a system of regulation would function in practice. Our model assumes full information, no informational assymetries nor any moral hazard, and also that both parties agree on the transition probabilities θ, and P. If these conditions were not satisfied, then it may yet turn out that rate of return regulation were more robust than the potentially superior but more delicate state–contingent price regulation.

VI Inefficient choice of techniques and the reverse Averch–Johnson Effect

The sustainability of rate of return regulation against shortfalls in demand depends on the size of (c–b)/rv, or the ratio of current cost savings to the capital costs. It is quite possible for c > d+rw > b+rv, where (d, w) = (variable cost, capital per unit output) describes an alternative less efficient, but also less capital–intensive technology with w < v.[12] (Gas turbines rather than baseload thermal, for example). It is also possible that (c–d)/rw > (c–b)/rv, and that (b, v) is not sustainable whilst (d, w) is. In that case the inefficiency might take the form of selecting an insufficiently capital–intensive technolgy rather than investing in too little capacity.

[12] If (b, v) is to be efficient for expansionary investments in good states, compared to (d, w), then $(d-b)(1-\sigma\theta P) > r(v-w)$. Thus if b = 2, rv = 5, d = 5, rw = 3, $\sigma\theta P < 1/3$.

The standard Averch–Johnson effect postulated that utilities subject to rate of return regulation and paid a rate of return above the cost of capital would have an incentive to select excessively capital intensive technology or to overinvest. In the present case this temptation is balanced by the fear that excessive capital intensity will induce the regulator to lower the allowed rate of return and cause the utility losses. It would be pleasing if these two counteracting forces balanced, leading to socially efficient choices of capital intensity, but there are no strong reasons to believe this will happen. Rather, in periods of rapid and stable demand expansion, the standard A–J effect is likely to dominate, whilst in periods of stagnant and unstable demand, the reverse effect may well predominate. This is at least a plausible interpretation of the pre– and post oil shock periods of regulation.

VII Conclusions

Has the implicit regulatory contract failed? The tightness of regulatory constraint changed significantly in the past two decades relative to the period of sustained growth that occurred in the years after WWII (see Joskow, 1974). These events could be consistent with either of the equilibrium outcomes discussed in Sections III and IV. We showed that an efficient investment path could be sustained as a UUROR equilibrium, with high returns in "good" states and low returns in "bad". One could interpret the early postwar period as a sustained "good" state, followed by a more recent prolonged "bad" state. Alternatively, one could apply the model in Section IV and conclude that there has been a breakdown of the efficient contract, and perhaps a movement to an underinvestment equilibrium.

A survey of planned electric powerplant investments in the past two decades suggests that there has been a movement toward underinvestment. Excluding hydro and geothermal projects, which are in limited supply, in 1977, electric power utilities had more than 650 projects in the planning stage, of which about one–half were more than 500 megawatts in size. In 1986, the total number was 64, of which 7 were more than 500 megawatts. Much of this ten–fold reduction is the consequence of excess capacity resulting from the exuberant construction program of the 1960s and early 1970s. However, the sharp change in capital intensity suggests that utilities are following a risk–minimizing approach of building for a low level of demand and relying on smaller plants with shorter leadtimes in the event of greater than anticipated demand growth. This pattern of investment, along with regulatory behavior that has granted rate increases with reluctance, with liberal use of "prudence review", suggests a regulatory environment that is not inconsistent with the "weak deviation" scenario described in Section IV. Regulated prices are adequate to compensate utilities for their investments in the event that demand is adequate to assure a high level of capacity utilitization. Utilities can make this situation more likely by underinvesting in base load facilities, and relying on relatively risk–free investment in small scale facilities in the event that more capacity is needed.

The doctrine of "used and useful" allows regulators to withhold payment on capital that does not provide direct benefits to ratepayers, and this could be applied to utilities with large amounts of excess capacity or to cancelled plants. When expenditures can be excluded from the rate base, rate of return regulation assumes characteristic of price regulation, where revenues are paid only on capital that is employed in production. We show that the flexibility to engage in "used and useful" rate of return regulation has mixed benefits. It is necessary to avoid the capitalization bias inherent in strict rate of return regulation. But the opportunity to withhold compensation can undermine the credibility of regulation and encourage undervestment by the utility. The problem is more severe when the regulator is enjoined from expropriating capital that is actually used (but can expropriate excess capacity), because the utility can safely invest to meet only base load demand.

Both the utility and the regulator can take actions that make expropriation less likely and therefore contribute to a sustainable regulatory contract. By choosing a production technique that is less capital intensive (and has higher operating costs), the utility can reduce the gain to the regulator from expropriation and mitigate the risk to itself should expropriation occur. Of course this implies that the regulatory bias will be in the direction of too little, rather than too much, capital investment. The regulator can make expropriation of the utility's sunk capital stock less attractive by refusing to protect itself from adverse consequences of supply shortages. For example, the regulator can choose not to enter into purchase power agreements that would provide back–up power at a reasonable price in the event that the utility fails to invest. Not investing in interconnections with other grids or utilities would be an even stronger commitment to the regulatory compact. While this has the paradoxical result that facilitating the exchange of power across regulatory jurisdictions could have adverse consequences for efficient regulatory behavior, it is also an unreasonable policy, if only because some interchange of power is necessary to provide security in the event of forced outages.

This paper departs from a recent trend in the economics of regulation which emphasizes the importance of asymmetric information in a natural monopoly environment. The regulator must provide incentives for the firm to reveal its private information. If the regulator is interested in total economic surplus (regardless of its distribution), or if the regulator is "captured" as described by Stigler (1971) and Peltzman (1976) by the interests of the regulated industry, there are mechanisms such as those suggested by Loeb and Magat (1979) that are sufficient to achieve efficient revelation of information according to the regulator's objectives. If, however, the regulator's objectives are dominated by consumer interests, the elicitation of private information entails costs.

It is in such a political environment where consumer interests dominate regulatory behavior that sunk costs pose difficulties for efficient investment. Thus, whenever there are sunk costs, to the extent that there are problems of asymmetric information in the regulatory contract, the difficulties described in this paper will be present as well. Furthermore, we believe that the changing regulatory environment can only be adequately appreciated in a Markovian setting, with its differing incentives for opportunism in good and bad times. Our model, though simple, captures these essential features of the regulatory relationship.

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Appendix

The value functions for the two state Markov process can be computed as follows. Let U^g, U^b, be the one–period returns in the good and bad states respectively, and let V and W be the present discounted value of future returns starting in a good or bad state respectively, with the transitions as described by (1). Then

$$V = U^g + \beta(1-\theta P)V + \beta\theta PW,$$
$$W = U^b + \beta(1-P)V + \beta PW,$$

where in each case the second term is the expected present value of moving to the good state, and the third term is the expected present value of moving to the bad state. These two simultaneous equations can be solved for V and W:

$$V\psi = U^g + \frac{\beta\theta P}{1-\beta P} U^b,$$

$$W\varphi = U^b + \frac{\beta(1-P)}{1-\beta(1-\theta P)} U^g.$$

where

$$\psi = 1 - \beta(1-\theta P) - \frac{\beta^2\theta P(1-P)}{1-\beta P} = \frac{(1-\beta)\{1-\beta P(1-\theta)\}}{1-\beta P},$$

and

$$\varphi = 1 - \beta P - \frac{\beta^2\theta P(1-P)}{1-\beta(1-\theta P)} = \frac{(1-\beta)\{1-\beta P(1-\theta)\}}{1-\beta(1-\theta P)}.$$

For example, consider the value to the regulator of retaining rate of return regulation rather than expropriating all the returns to capital under UUROR.

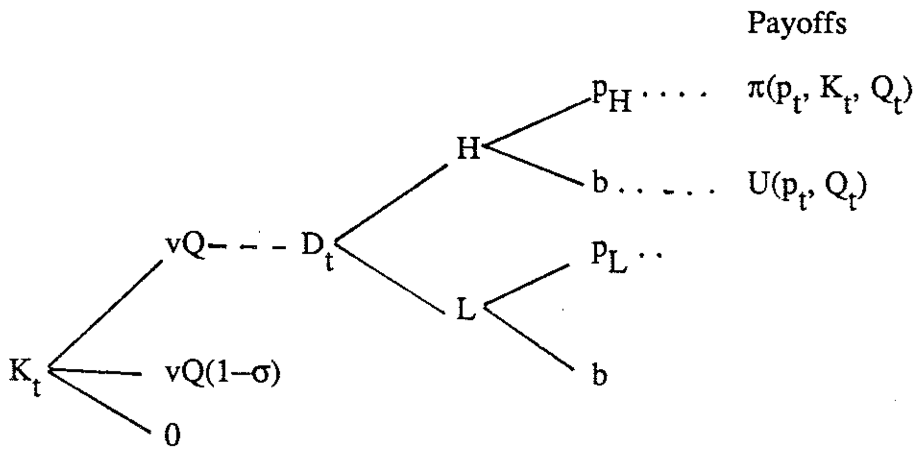
$$U^g/Q = (c-b-rv)(1-\sigma) + \sigma\{(c-b)(1-\theta P) - rv\},$$

$$U^b/Q = (1-\sigma)(c - b - rv).$$

The one–period gain from expropriating is $rvQ + \rho\sigma vQ$ in state GH, and $rvQ - \mu\sigma vQ$ in state GL, and neither action will be worthwhile if

$$rvQ + \rho\sigma vQ \leq \beta V^r; \;\; rvQ - \mu\sigma vQ \leq W^r.$$

The borderline case will be when both conditions are satisfied with equality, which, together with $\rho = \mu\theta P/(1-\theta P)$, gives three equations in three unknowns, ρ, μ and $\xi \equiv (c-b)/rv$. Let the solution be ξ^*. The if $\xi \geq \xi^*$, $\{(r,s,s'); (vQ,vQ(1-\sigma)\}$ is a SPNE. If $\xi^* > \xi > 1/\beta$, then there is a K^*, $vQ > K^* > vQ(1-\sigma)$, such that $\{(r,s,s'); (K^*,vQ(1-\sigma)\}$ is a SPNE – the benefits of expropriating in GH will now be $rvQ(1-\sigma) + \{K^*-vQ(1-\sigma)\}(r+\rho) = \beta V^r$, which will allow a higher value of ρ, μ than vQ.



Utility chooses capital in t	Demand is realized	Regulator chooses price	Utility chooses output

Table 1 Basic Regulation Game

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