LUMPY INVESTMENT, CAPITAL RECOVERY, AND RATE SHOCK:

Comparing Rate of Return Regulation and Price Caps*

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*Abstract*

Rate-of-return and price-cap regulation are compared with unregulated monopoly when scale economies in plant construction warrant lumpy investments. Steady-state price paths and the size and frequency of investments are examined. Rate-base regulation expands both the peak capacity and the cycle length. Though the firm undertakes larger projects, average capacity may fall, casting doubt on the validity of cross-sectional tests of the over-capitalization hypothesis. By frontloading capital recovery, it can also cause a "rate shock" even though regulators follow rules of "economic" depreciation. In contrast, price-cap regulation avoids rate shock entirely, though it permits monopoly pricing early in the investment cycle. In addition, it tends to push investment in the same direction as optimal regulation. An informal analysis of learning-by-building and embodied technical progress in plant construction demonstrates that the advantage of price caps is less clear. On balance, however, the promise of superior allocative efficiency and acceptable distributional properties gives the edge to price caps.

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## 1. INTRODUCTION

Traditionally, rate regulation is defended as a legitimate means to restrain market power that derives from economies of large-scale production. Invariably these economies are of a simple static variety owing to fixed costs of operation. Often overlooked, increasing returns in plant construction is another source of natural monopoly. This scale economy warrants large, periodic additions to capacity which result in a perpetual mismatch between current capacity and ideal output. Too much capacity is on hand immediately following an expansion, while growing demand and aging facilities lead to a shortfall later on.

Construction economies are pervasive in many public utilities. This is especially true of the electric power industry. A typical hydro-electric or nuclear powerplant represents a substantial amount of generating capacity even relative to a regional power grid. Similarly, completion of bulk power facilities dramatically expands transmission capacity along a given path.[1]

Due to their immobility and specialization, these investments also tend to be highly sunk. Sunkness poses additional problems. To begin with, even in the absence of strong economies, an incumbent can exploit its lower avoidable costs to exclude entrants from the market. Should regulators step in to curb monopoly excesses, they must then decide how to value the firm's investments whose opportunity cost has fallen to near zero.

The challenge before regulators is to erect the proper incentives for investors to undertake these large projects, and at the same time to finance them without creating significant inequities among ratepayers. In practice, utility regulation closely links price with the firm's invested capital, as when the project's rate of return is constrained by some upper limit.

Recent experiments with price cap regulation offer an alternative approach in which an index of a basket of services is constrained by a ceiling.

In this paper I compare the performance of these two policies against the alternative of unregulated monopoly when investment is lumpy. I examine the impact of lumpiness on the path of regulated prices. My principal concern, however, is with regulation's effect on the size and frequency of investment projects.

To preview, it is easy to see how rate-base regulation works at cross purposes with allocative efficiency.[2] Soon after a lump is added, capacity begins to depreciate. This causes operating expenses to grow as the firm substitutes other productive factors while awaiting the next investment. The shrinking rate base supports a smaller revenue requirement and hence lower prices. Although rising operating costs counteract this tendency, it may not be sufficient to prevent a "rate shock" in which price takes a discrete, upward jump as the next lump is added. In comparison, the efficient solution requires price to rise gradually over the cycle, only to drop as new capacity comes into service.

Under plausible conditions, I find that the firm undertakes projects that are larger than its unregulated counterpart. These projects occur less frequently, however. Consequently, the regulated firm need not be more capital intensive than an unconstrained monopolist, the typical conclusion from the literature.

An ever-popular means of rate control, price ceilings have recently undergone a modification. Renamed "price cap regulation," this hybrid policy sets an upper bound on an index of prices for a basket of services. A formula adjusts the ceiling over time to account for general price inflation, improvements in productivity, and changes in tax laws and accounting standards. By decoupling the ceiling from the firm's performance, owners capture the full value of any cost reduction. Thus, price caps allow the regulated firm considerable pricing flexibility while they provide strong incentives to operate efficiently (see Vogelsang (1988)).

Price cap plans have become an integral part of the privatization movement taking place in many public enterprises in the United Kingdom. Some form has already been applied to the British telephone, water, natural gas, and electric power industries. In the United States, the Federal Communications Commission replaced the current system of rate-of-regulation of long-distance telephone service with a price cap scheme.

Proposals to apply price caps to the generation and distribution of electric power are currently under consideration in this country at both the state and federal levels.[3] In one instance a form of price-cap regulation was imposed by the California Public Utilities Commission on the Diablo Canyon nuclear plant. An unprecedented settlement negotiated by the Division of Ratepayer Advocates with the plant's owner, Pacific Gas & Electric, established a ceiling on the rates for power generated at this station over an estimated 30-year lifetime. Initially, the ceiling will increase at a fixed rate; thereafter it will track the consumer price index. In part this plan was intended to reduce the rate shock anticipated had the plant entered the rate base as usual.

To compare the regulatory alternatives, I build a simple model of production with lumpy investment. Solving profit maximization and welfare maximization problems establishes benchmarks for regulated outcomes. In the process, different patterns of capital recovery implied by the pricing solutions emerge. Modifying the usual rate-of-return constraint to allow for lumpiness, I derive conditions on the regulated firm's price and investment decisions. The same is done for price cap regulation. Extending the original model somewhat, I proceed to weigh the relative merits of the two schemes when plant construction undergoes technical change. I finish with some policy implications for price and investment regulation of investor-owned utilities.

## 2. A MODEL OF LUMPY INVESTMENT

Demand for a single service is stable over time. Denote the downward sloping demand price by $P(q)$. The absence of income effects guarantees that Marshallian surplus is an accurate measure of (instantaneous) consumer welfare. Write the gross surplus as $S(q) \equiv \int_0^q P(x)dx$. The firm's revenue $R(q) = P(q)q$ is assumed to be concave, reaching a single peak. The interest rate $r$ serves as both the private and social rate of discount.

Production requires the services of both durable capital and variable factors. Completed plants are purchased at cost and installed without any lag--as was the case for powerplants during nuclear power's "turn-key era." As usual, plants of different vintages are fungible and they *physically* depreciate at the constant rate $\delta$. I also make the standard assumption that capital is perfectly divisible. This ensures that any lumpiness in capacity expansion occurs endogenously and not as an artificial restriction. Lastly, once in place, all capacity is sunk.

Construction technology exhibits increasing returns at least for small scale plants. Eventually plant costs will rise as long project lead-times incur ever-mounting interest charges. A U-shaped average construction cost curve captures these properties. Denoting *project size* by $I$, let its cost be $C(I) = B + c(I)$ where $c' > 0$, $c'' > 0$, $c''' > 0$. Thus scale economies enter only through the fixed project cost $B$.

I limit the analysis to stationary solutions having an infinite sequence of identical cycles of price and investment--a rather weak restriction given stable demand and cost conditions. If *peak capacity* at the start of a cycle immediately following investment is K, then a *base capacity* of $Ke^{-\delta T}$ remains after a *cycle length* of T. Together, K and T completely determine the project size: $I = (1 - e^{-\delta T})K$. Lumpiness causes the capital stock to oscillate: $k(t) = Ke^{-\delta t}$ for $t \in [(n-1)T, nT)$ where cycles are indexed by $n = 1,2,\ldots,\infty$. Several cycles are depicted by the saw-tooth pattern in Figure 1.

[FIGURE 1 ABOUT HERE]

I will also be interested in the regulatory effects on *average capacity*. A natural measure is an unweighted average capacity over a complete cycle:

$$(1) \qquad A = \frac{1}{T}\int_0^T Ke^{-\delta t}dt = \frac{K(1-e^{-\delta T})}{\delta T} = \frac{I}{\delta T}$$

Clearly, average capacity rises with K; less obvious is the fact that it falls with T.[4]

Let $V(q,k)$ be the minimum variable cost of providing the flow of service q from capital stock k. Expenditures on maintenance and repair of plant and equipment could be included in this figure provided the charges were independent of the age of the capital. Decreasing returns to scale in short-run production ensures that V is convex in $(q,k)$. Capital is assumed to be an essential input into production (i.e., $V(q,0) = \infty$). Under standard regularity conditions, operating cost rises with output as capital is substituted for variable factors (i.e., $V_q > 0$). Finally I make the crucial but plausible assumptions that expanded capacity drives down operating cost at decreasing rate (i.e., $V_q > 0$, $V_{qk} < 0$). The last condition implies that capital is a *normal* factor of production.

## 3. OPTIMAL PRICING, INVESTMENT, AND CAPITAL RECOVERY

To assess the effects of regulation, I need a benchmark for comparison. Consider the following measure of discounted welfare:

$$(2)\quad W(K,T,q(\cdot)) = \frac{1}{1-e^{-rT}}\left\{\int_0^T\left[\rho S(q(t)) + (1-\rho)R(q(t)) - V(q(t),Ke^{-\delta t})\right]e^{-rt}dt - C((1-e^{-\delta T})K)\right\}$$

where $\rho \in [0,1]$ gives the relative weight assigned to investors and customers. The factor outside the brackets was derived by discounting each cycle back to the initial time:

$$(3)\quad \sum_{n=0}^{\infty} e^{-nrT} = \frac{1}{1-e^{-rT}}$$

Notice that (2) ignores the cost of accumulating the base capacity (i.e., $Ke^{-\delta T}$) that is necessary to start out at a stationary outcome.

We seek to choose $q(t)$, $K$ and $T$ to maximize (2). I first find the optimal static price at time $t$ given capital stock $k(t)$. Because it depends only on capital stock (and not, say, on its utilization rate), the static solution also solves the long-run pricing problem.

### 3.1 Short-Run Pricing and Capital Recovery

Optimal output can be expressed as a simple function of current capital stock, $q^*(k(t))$. It calls for a mark-up of price over marginal operating cost:

$$(4)\quad \frac{P(q^*(k)) - V_q(q^*(k),k)}{P(q^*(k))} = \frac{\rho}{\varepsilon(q^*(k))}$$

Notice that $\rho$ behaves just like the so-called Ramsey number. The time path of prices is then given by $p^*(t) = P(q^*(Ke^{-\delta t}))$. Straightforward computation shows that, under the assumptions on variable cost, price rises over the cycle as scarce capital pushes up marginal (operating) cost. As each new cycle arrives, the price drops precipitously. This pattern is inscribed in Figure 1.

It is a simple matter to show that the *monopoly quasi-rent* $\hat{\pi}(k) \equiv \max_q \{R(q) - V(q,k): q > 0\}$ rises with capital stock and, hence, declines over the course of a cycle. The pattern of quasi-rents determines the speed of recovery of the capital outlay.

Hotelling (1927) argued that the economic value of an asset must equal the discounted returns generated over its remaining lifetime. This rule applies even when the asset is completely sunk. He went on to define economic depreciation as the change in this value over time. In my notation:

$$(5) \qquad D(t) = \pi(Ke^{-\delta t}) - r\int_t^T \pi(Ke^{-\delta\tau})e^{-r(\tau-t)}d\tau$$

where $\pi$ is quasi-rent under an arbitrary rate schedule. Differentiating this expression gives the time pattern of depreciation:

$$(6) \qquad D'(t) = rD(t) - \delta Ke^{-\delta t}\pi'(Ke^{-\delta t})$$

Hence, if the quasi-rent declines with capital stock, depreciation increases over the cycle; that is, capital recovery is "backloaded." If the quasi-rent increases, as with monopoly pricing, then the pattern of depreciation is unclear. Under Ramsey pricing this is certainly true since:

$$(7) \qquad \frac{d\pi^*}{dk} = \rho P'(q^*))q^* \frac{dq^*}{dk} - V_k \gtrless 0$$

where $\pi^*$ represents the quasi-rent under optimal pricing.

While it is merely a bookkeeping practice to apportion the cost of durable investments over time, depreciation can have significant allocative consequences. When linked to prices through taxation or regulation, a depreciation schedule can distort market signals that guide managerial decisions.

### 3.2 Size and Timing of Lumps

Turning to the investment problem, the optimal selection of steady-state size and frequency of projects amounts to a limiting case of the problem solved by Starrett (1978). Therefore the details are omitted. Importantly, even though the short-run technology exhibits decreasing returns, optimal prices may not generate sufficient revenue to recover the full cost of a lump. In that event judicious choice of the weight $\rho$ will return the enterprise to solvency.

The extreme case $\rho = 1$ corresponds to profit maximization. Then (3) reduces to the familiar monopoly mark-up rule. Substituting monopoly output [i.e., $\hat{q}(Ke^{-\delta t})$] back into the expression for profit and differentiating yields first-order conditions with respect to peak capacity and cycle length:

$$\frac{\partial \hat{\Pi}}{\partial K} = \frac{1}{1-e^{-rT}}\left[-\int_0^T \hat{V}_k e^{-(\delta+r)\tau} d\tau - (1-e^{-\delta T})c'(I)\right] = 0 \tag{8}$$

$$\frac{\partial \hat{\Pi}}{\partial T} = \frac{re^{-rT}}{(1-e^{-rT})^2}\int_0^T\left[\hat{R} - \hat{V} - C(I)\right]e^{-r\tau}d\tau + \frac{1}{1-e^{-rT}}\left\{\left[\hat{R} - \hat{V}\right]_T e^{-rT} - \delta K e^{-\delta T}c'(I)\right\} = 0 \tag{9}$$

where a hat ^ indicates that a function is evaluated at monopoly prices. Denote the solutions to (8) and (9) as $\hat{K}(T)$ and $\hat{T}(K)$, respectively.

The rule for choosing peak capacity equates the marginal cost of construction to the marginal savings of variable factors, both appropriately discounted. Increasing returns in capacity construction is offset by interest charges. Even with strong scale economies (i.e., large B), investment will recur because of the prohibitive "holding cost" of maintaining enough capacity to meet all replacement needs in the future. Only in the extreme case when construction costs are invariant to the size of the project (i.e., $c(\cdot) \equiv 0$) would all investment take place once and for all at the outset.

In order to perform the desired comparative statics exercises, it is crucial to know whether profit-maximizing project size and cycle length are directly or indirectly related. Though impossible to prove without further restrictions, I assume that a profit-maximizing firm's selection of peak capacity increases with the length of the investment cycle, and vice versa. This is a reasonable assumption for suppose the monopolist is forced to extend the time between lumps. This could result from an expanded lag between rate reviews. Then, for a fixed peak capacity, project size will necessarily increase and average capacity will fall. The firm can offset this change in its capital program by raising its peak capacity. As a result $\hat{K}(T)$ will increase with T. A similar intuition concludes that $\hat{T}(K)$ is increasing in K. In this case it is shown in Woroch (1987) that:

PROPOSITION 1: *Relative to monopoly solution, optimal price and investment calls for a larger peak capacity and a shorter cycle length. While the effect on project size is uncertain, the average capacity rises.*

## 4. RATE-BASE REGULATION

Rates charged by investor-owned electric power companies and other public utilities typically are constrained so as not to earn a rate of return on invested capital above a prescribed level. Three ingredients are needed to implement this regulatory constraint: the value of the rate base, a rule for calculating depreciation expense, and the choice of an allowed return on investment.

### 4.1 The Regulatory Constraint

Several methods have been employed by regulatory commissions to value the firm's rate base. In the early days of regulation, historical cost of plant and equipment was commonly used. Today commissions show a preference for averaging it with replacement value, producing the so-called "fair market value." Here, the rate base is calculated at replacement cost, $C(Ke^{-\delta t})$. This measure agrees with Hotelling's notion of asset value as long as there is a competitive market in the supply of new capital goods.

Economic depreciation simply equals the change in the value of the rate base. Because no investment occurs during the cycle, depreciation is exactly $D(t) = \delta Ke^{-\delta t}c'(Ke^{-\delta t})$. Since $D'(t) < 0$, this scheme will *frontload* capital recovery.[5]

For the purpose of expressing the rate-of-return constraint, I treat depreciation as an operating expense. The constraint facing the firm then becomes:

$$(10) \qquad R(q) - V(q,Ke^{-\delta t}) - \delta Ke^{-\delta t}c'(Ke^{-\delta t}) \leq \bar{r}C(Ke^{-\delta t})$$

where $\bar{r} > r$ is the *allowed* rate of return. Equivalently an upper bound is placed on the utility's cash flow $R(q) - V(q,k)$ equal to the sum of depreciation expense and an allowed return on invested capital: $b(k) \equiv \delta kc'(k) + \bar{r}C(k)$.

Notice that the constraint is assumed to hold continuously. This is realistic if the time between rate reviews is much shorter than the investment cycle, a plausible assumption given the long lifetimes of the investments under consideration.[6]

4.2 Pricing and Investment Under the Constraint

Once again, divide the firm's problem into a short-run pricing part and a long-run investment part. Given K and T, k(t) is determined, in which case the firm sets price to solve:

$$\bar{\pi}(k) = \text{Maximize } R(q) - V(q,k) \qquad (11)$$
$$\text{Subject to: } R(q) - V(q,k) \le b(k)$$

To get a handle on the solution, consider the unconstrained problem separately. The value of that program is just the monopoly quasi-rent $\hat{\pi}(k)$ which is increasing and concave in capital stock. Now under the assumptions on $c(\cdot)$, the cash-flow constraint $b(\cdot)$ is increasing and convex. Both the regulated return and the quasi-rent are plotted in Figure 2. Clearly, if the constraint binds at all, it does so over a single, closed interval. When it binds, the production plan of the firm is indeterminate. In that event, assume the firm produces the largest output consistent with the constraint, namely $q_0(k) = \max\{q: R(q) - V(q,k) \le b(k)\}$. The firm's production plan is then:

$$\bar{q}(k) = \begin{cases} \hat{q}(k) & \hat{\pi}(k) \le b(k) \\ q_0(k) & \hat{\pi}(k) > b(k) \end{cases} \qquad (12)$$

Here $q_0(k) > \hat{q}(k)$ for $k \in (k_\ell, k_u)$ where $k_\ell$ and $k_u$ are the critical levels of capacity where the monopoly quasi-rent hits the allowed rate of return. They are the smallest and largest roots, respectively, of the equation $\hat{\pi}(k) = b(k)$.

[FIGURE 2 ABOUT HERE]

To see how rate shock could occur, notice that $\hat{q}(k)$ is decreasing in $k$ but that $q_0(k)$ need not be. It is possible that $q_0(Ke^{-\delta T}) > \hat{q}(K)$, or equivalently, $p(0) > p(T-\varepsilon)$ for $\varepsilon$ arbitrarily small. A significant rise in price is not necessary, however, for a large loss in allocative efficiency. The second-best rule $q^*(k)$ has price *rising* over the cycle culminating in a sudden *drop* in price as each new plant is added.

Given K, define the points in time $t_\ell$ and $t_u$ at which capital stock hits the critical levels $k_\ell$ and $k_u$:

$$(13) \qquad k_\ell = Ke^{-\delta t_\ell(k)}$$

$$(14) \qquad k_u = Ke^{-\delta t_u(k)}$$

I assume that the rate-of-return constraint begins to bind some time after a lump is added. In other words, so much capacity is on hand after an investment that even (short-run) monopoly profits fall below the allowed return. I also assume that the constraint relaxes before the end of the cycle when the scarce capacity supports only a low return. Under these conditions, the regulated firm's objective becomes:[7]

$$(15) \text{ Maximize } \overline{\Pi}(K,T) = \frac{1}{1-e^{-rT}}\left[\int_0^{t_u} \hat{\pi}(Ke^{-\delta t})e^{-rt}dt + \int_{t_u}^{t_\ell} b(Ke^{-\delta t})e^{-rt}dt + \int_{t_\ell}^{T} \hat{\pi}(Ke^{-\delta t})e^{-rt}dt - C((1-e^{-\delta T})K)\right]$$

Comparing the first-order conditions from this problem with (8) and (9) above, it is shown in the Appendix that:

PROPOSITION 2: *The regulated firm is induced to undertake larger investment projects than without regulation; on the other hand, investment occurs less frequently than under monopoly. Consequently, the project size is larger.*

Figure 3 illustrates the proposition. Its conclusion deviates from the conventional wisdom regarding this brand of regulation: since a smaller average capacity cannot be ruled out, *rate-of-return regulation may not result in more capital intensive production*.

[FIGURE 3 ABOUT HERE]

## 5. PRICE CAP REGULATION

Price-cap regulation described in the Introduction takes a particularly simple form when investment is lumpy. It reduces to a fixed ceiling on price since industry demand and cost conditions are assumed to be unchanging. Let $\bar{p}$ be that ceiling. Then whatever investment policy the firm follows, it will set the monopoly price $\hat{p}(Ke^{-\delta t})$ unless this exceeds the ceiling. If the ceiling is at all effective, this will occur at some time during the cycle $\bar{t}$ when $\hat{p}(Ke^{-\delta\bar{t}}) = \bar{p}$. A bold regulated price path is superimposed on the monopoly path in Figure 4.

[FIGURE 4 ABOUT HERE]

The firm's profit becomes:

$$(16) \qquad \bar{\Pi}(K,T;\bar{p}) = \frac{1}{1-e^{-rT}}\left\{\int_0^{\bar{t}}\hat{\pi}(Ke^{-\delta t})e^{-rt}dt + \int_{\bar{t}}^{T}[R(\bar{Q}) - C(\bar{Q},Ke^{-\delta t})]e^{-rt}dt\right\}$$

where $\bar{Q}$ is shorthand for $Q(\bar{p})$. At the moment the ceiling binds, the rate of economic depreciation accelerates. This can be seen by comparing the marginal quasi-rent that appears in (6) by its value before and after the ceiling is reached. While monopoly pricing prevails, the marginal quasi-rent equals $\pi'(Ke^{-\delta\bar{t}-\varepsilon}) = - V_k(Q(\hat{p}(\bar{t}),Ke^{-\delta\bar{t}-\varepsilon}) > 0$. Using the fact that $V_{qk} < 0$ and $\hat{p}(\bar{t}-\varepsilon) < \bar{p}+\varepsilon$, this is larger than when the ceiling binds, namely, $- V_k(\bar{Q},Ke^{-\delta\bar{t}+\varepsilon})$. Hence, $D'(t)$ is larger immediately after the switch point than immediately before. While this does not establish whether capital recovery will speed up or slow down over the cycle, there is a greater tendency to backload depreciation than under unregulated monopoly.

Unlike pricing, the effect of price caps on investment policy is not so straightforward. Intuitively, by clipping off the high prices at the tail end of the cycle, one would expect the firm to curtail its investment because of the reduced earnings. On the other hand, the overall pattern of price tends to be closer to competitive levels, and a price-taking firm will invest more heavily in plant and equipment. As we will see, the latter reasoning prevails.

In the Appendix, first-order conditions for the regulated peak capacity and cycle length, $\bar{K}$ and $\bar{T}$, are derived and compared with the unregulated solution. It is shown that:

PROPOSITION 3: ***As the price ceiling is reduced, the regulated firm undertakes projects with larger peak capacity but shorter cycle length; hence, average capacity will rise but the effect on project size is ambiguous.***

Notice that price cap regulation affects the monopolist's construction program in the same way as optimal price regulation. It is more difficult to compare pricing, however. Behaving like a monopolist, the firm sets price too high during the early part of the cycle. After the ceiling is reached, price is held down below the unregulated outcome. When the next lump is added, price will jump down, just as with the efficient solution. Thus price ceiling regulation tends to alter both price and investment in the preferred direction.[8]

## 6. COMPARING TECHNICAL PROGRESS

Besides the size and timing distortions, technical progress of the firm should be taken into account to gain a more complete picture of the effects of intervention. Since no allowance was made for technical change in the model, however, any conclusions about the firm's dynamic performance are merely impressionistic.

Suppose that construction costs automatically fall with each new project. The presence of such "learning-by-building" was empirically verified by Zimmerman (1982) for the case of nuclear powerplants. Among other results, he found that an electric utility's plant cost fell the more plants it had built in the past and the longer the time these plants were under construction.

Translating this phenomenon to the present context, I conclude that a firm with (i) a shorter investment cycle, and (ii) a larger project size will enjoy faster reductions in construction costs. First, since projects occur more frequently under price caps, they gain an advantage over rate-base regulation. On the other hand, a rate-of-return constrained utility will undertake *larger* projects, and if larger plants take *longer* to complete, it will regain some of its loss in technical advantage.

Cost reductions may also come about from technical improvements that are unrelated to a firm's construction program. Developments in generation technology and power engineering occur continuously. A utility can take advantage of these exogenous advances by incorporating the best practice in each new vintage. Then at any moment in time, the operating efficiency of accumulated capital depends on the distribution of vintages in its current inventory of plants.

Efficiency will depend on the sum of different vintages weighted by their size. In fact, the longer the cycle, the greater the proportion of the most recent vintages in the capital stock.[9] Here, rate-base regulation will tend to out-perform price cap regulation since it tends to expand time between investments.

## 7. IMPLICATIONS FOR REGULATORY POLICY

The consequences of lumpy investment derived above have immediate policy implications for regulation of investor-owned utilities. I begin with the issues surrounding price control.

### 7.1 Price Regulation

It was seen how rate-base regulation may cause price to fall over the investment cycle as the rate base declines. This pattern not only harms allocative efficiency, but it may also have a detrimental effect on intergenerational equity. Especially with long-lived investments like nuclear powerplants, the firm will experience considerable turnover in its customer base. The individuals who shoulder the burden of rate shock may not be around years later to enjoy the compensating reductions.

In its defense, rate-base regulation holds out some promise for rate stability. It creates two offsetting tendencies--shrinking rate base and rising operating costs--which tend to cancel one another, thereby flattening the price profile. If there are social benefits associated with reduced price variability not captured in the social objective function, rate-base regulation could partially compensate for its many other drawbacks with greater price stability.

It is somewhat odd that Boiteux looked favorably on such stable price paths when investment is lumpy. He claims that "The need to keep rates steady ... makes long-term policy preferable to the *instantaneous* optimum use of investment; the underlying principle of this is *to fix rates equivalent to what the differential cost would be if the plant were constantly at correct capacity*."[10] Rate-base regulation stabilizes prices, and yet it is antithetical to the marginal principles which Boiteux promoted on so many occasions.

In recent years commissions have improvised on the standard rate-base method in an attempt to smooth out abrupt rate changes.[11] Nowhere has the need for reform been greater than in the nuclear power generation. Rates skyrocket soon after a nuclear plant is certified as "used and useful" as billions of dollars are suddenly dumped into the rate base.

Without abandoning the rate-of-return methodology, regulators have attempted to spread out the bulge in capital recovery over a number of years. The impact of a large new plant is pushed ahead in time by allowing Construction Work in Progress (CWIP) into the rate base. To further soften the blow, "negative CWIP" removes some or all of the CWIP from the rate base after completion according to a schedule that "mirrors" the original construction timetable.

Departing from the standard review process are the accounting practices which include "deferred trending" and "indexed borrowing." Essentially, these schemes simply flatten rates by clipping off the peak and deferring it until later.

The many attempts to repair rate-of-return regulation point to a fundamental inadequacy of this policy, and warrant a look at the alternatives. Price caps share many desirable properties with the second-best pricing schedule. Just as rate-base regulation, price caps tend to stabilize price. In other contexts they have been shown to promote efficient relative prices and to support cost-efficient production (Vogelsang (1989)). Of course, a complete comparison of the allocative properties requires more detailed examination of the relative performance of the two policies, such as simulation of the outcomes under various demand and cost conditions as in Park (1989). For now, we can rest assured that price caps have many attractive advantages over rate-base regulation.

### 7.2 Investment Regulation

Turning to investment issues, recall that rate-base regulation induced the firm to undertake larger but less frequent projects. And in contrast, although price caps fall short of the second-best optimum, they drive investment policy in the same direction.

There has always been a concern over investment distortions caused by this form of regulation. Averch and Johnson (1962) theoretically verified a long-held suspicion that rate-of-return regulation induced excessive investment in rate base. Over-capitalization persists with lumpy investment but takes on a special character: the firm undertakes larger projects when regulation is applied, but the effect on the average capacity remains indeterminate. Larger projects go hand-in-hand with higher peak capacity and lower base capacity.

This leads us to reconsider empirical tests of the over-capitalization hypothesis. One cannot draw conclusions from a single "snapshot" of the firm's capital structure. Cross-sectional data cannot fully capture capital intensity: an unambiguously more capital-intensive production plan--one having larger peak capacity <u>and</u> a shorter investment cycle--will have a smaller capital stock over some period of time. Possibly lumpiness in capacity explains the mixed results from empirical tests of this result.

## 8. CONCLUSIONS

The production technology of many public utilities required large, sunk investments in plant and equipment. Two regulatory institutions--rate of return regulation and price caps--have very different implications for price and investment with lumpy capital expansion. With some qualifications regarding the adoption of technical advances, price cap regulation displays superior allocative performance and acceptable distributional properties.

## APPENDIX

Derivation of PROPOSITION 2: Define $\bar{t}_u = \max(t_u(K),0)$ and $\bar{t}_\ell = \min(t_\ell(K),T)$. Note that $T$ affects $t_\ell$ but not $t_u$. Differentiation of (16) with respect to $K$ given $T$ yields the first-order condition:

$$\text{(A1)}\quad \frac{\partial\bar{\Pi}}{\partial K} = \frac{1}{1-e^{-rT}}\left\{\frac{\partial\bar{t}_u}{\partial K}\left[\hat{\pi}(Ke^{-\delta\bar{t}_u}) - b(Ke^{-\delta\bar{t}_u})\right]e^{-r\bar{t}_u}\right.$$
$$- \frac{\partial\bar{t}_\ell}{\partial K}\left[\hat{\pi}(Ke^{-\delta\bar{t}_\ell}) - b(Ke^{-\delta\bar{t}_\ell})\right]e^{-r\bar{t}_\ell} + \int_0^{\bar{t}_u}\hat{\pi}'(Ke^{-\delta t})e^{-(\delta+r)t}dt$$
$$\left.+ \int_{\bar{t}_u}^{\bar{t}_\ell}b'(Ke^{-\delta t})e^{-(\delta+r)t}dt + \int_{\bar{t}_\ell}^{T}\hat{\pi}'(Ke^{-\delta t})e^{-(\delta+r)t}dt - (1-e^{-\delta t})c'(I)\right\}$$

The first two terms always vanish: the derivatives are zero except when the terms in square brackets vanish. What remains will differ from $\partial\hat{\Pi}/\partial K$ in (8) by the amount:

$$\text{(A2)}\qquad \frac{\partial\bar{\Pi}}{\partial K} - \frac{\partial\hat{\Pi}}{\partial K} = \frac{1}{1-e^{-rT}}\int_{\bar{t}_u}^{\bar{t}_\ell}\left[b'(Ke^{-\delta t}) - \hat{\pi}'(Ke^{-\delta t})\right]e^{-rt}dt$$

First observe that the integrand in the second term is negative since $k_\ell \le \bar{k}_\ell < \bar{k}_u \le k_u$. Suppose that $\hat{K} > k_u$ and $\hat{T} > t_\ell$. Then $\bar{k}_u = k_u$ and $\bar{k}_\ell = k_\ell$ in which case the first term vanishes. Thus, at $(\hat{K},\hat{T})$:

$$\text{(A3)}\qquad \frac{\partial\bar{\Pi}}{\partial K} > \frac{\partial\hat{\Pi}}{\partial K}$$

Now fix K and differentiate with respect to T:

$$\text{(A4)}\qquad \frac{\partial\bar{\Pi}}{\partial T} = \frac{-re^{-rT}}{(1-e^{-rT})^2}\left[\int_0^{\bar{t}_u}\pi(Ke^{-\delta t})e^{-rt}dt + \int_{\bar{t}_u}^{\bar{t}_\ell}b(Ke^{-\delta t})e^{-rt}dt\right.$$
$$\left.+ \int_{\bar{t}_\ell}^{T}\hat{\pi}(Ke^{-\delta t})e^{-rt}dt - C(I)\right]$$

$$+ \frac{1}{1-e^{-rt}} \left\{ \left[ b(Ke^{-\delta \bar{t}_\ell}) - \hat{\pi}(Ke^{-\delta \bar{t}_\ell}) \right] e^{-r\bar{t}_\ell} \frac{\partial \bar{t}}{\partial T} \right.$$

$$\left. + \ \hat{\pi}(Ke^{-\delta T})e^{-rT} - \delta K e^{-\delta T} c'(I) \right\}$$

using the fact that $\bar{t}_u$ is independent of T. Provided that $t_\ell < T$, $\partial \bar{t}_\ell / \partial T = 0$ and therefore,

$$\text{(A5)} \qquad \frac{\partial \bar{\Pi}}{\partial T} - \frac{\partial \hat{\Pi}}{\partial T} = \frac{-re^{-rT}}{(1-e^{-rT})^2} \int_{\bar{t}_u}^{\bar{t}_\ell} \left[ b(Ke^{-\delta t}) - \hat{\pi}(Ke^{-\delta t}) \right] e^{-rt} dt$$

which is negative since $b > \hat{\pi}$ for $t \in (\bar{t}_u, \bar{t}_\ell)$.

Thus for any T such that $\hat{K}(T) > k_u$, then $\bar{K}(T) > \hat{K}(T)$, and for K such that $\bar{T}(K) > t_\ell(K)$ implies $\bar{T}(K) > \hat{T}(K)$. Hence, $\hat{K} > k_u$ and $\hat{T} > t_\ell(\hat{K})$ implies that $\bar{K} > \hat{K}$ and $\bar{T} > \hat{T}$. ∎

Derivation of PROPOSITION 3: The Envelope Theorem applied to the firm's unconstrained profit maximization problem shows that $\text{sign}(d\bar{K}/d\bar{p}) = \text{sign}(\partial^2\bar{\Pi}/\partial K \partial \bar{p})$ and $\text{sign}(d\bar{T}/d\bar{p}) = \text{sign}(\partial^2\bar{\Pi}/\partial T \partial \bar{p})$. Simple differentiation yields:

$$\text{(A6)} \quad \frac{\partial \bar{\Pi}}{\partial K} = \frac{1}{1-e^{-rT}} \left\{ \int_0^{\bar{t}} \hat{\pi}'(Ke^{-\delta t})e^{-(r+\delta)t} dt - \int_{\bar{t}}^{T} V_k(\bar{Q}, Ke^{-\delta t})e^{-(r+\delta)t} dt \right.$$

$$\left. - \ c'(I)(1 - e^{-\delta T}) \right\}$$

$$\text{(A7)} \quad \frac{\partial \bar{\Pi}}{\partial T} = \frac{re^{-rT}}{(1-e^{-rT})^2} \bar{\Pi} + \frac{1}{1-e^{-rT}} \left\{ [R(\bar{Q}) - C(\bar{Q}, Ke^{-\delta T})]e^{-rT} - \delta K e^{-\delta T} c'(I) \right\}$$

Using the fact that $\hat{\pi}'(k) = -V_k(\hat{q}(k),k)$, we have:

$$\text{(A8)} \qquad \frac{\partial^2 \bar{\Pi}}{\partial K \partial \bar{p}} = \frac{-1}{1 - e^{-rT}} \int_{\bar{t}}^{T} V_k(\hat{q}(Ke^{-\delta t}), Ke^{-\delta t}) Q'(\bar{p}) e^{-(r+\delta)t} dt$$

which is negative. Thus, as the price cap $\bar{p}$ comes down, the peak capacity $\bar{K}$ rises. Finally,

$$\text{(A9)} \qquad \frac{\partial^2 \bar{\Pi}}{\partial T \partial \bar{p}} = \frac{re^{-rT}}{(1-e^{-rT})^2} \int_{\bar{t}}^{T} [R'(\bar{Q}) - V_q(\bar{Q},Ke^{-\delta t})]Q'(\bar{p})e^{-rt}dt$$

$$+ \frac{e^{-rT}}{1-e^{-rT}} [R'(\bar{Q})-V_q(\bar{Q},Ke^{-\delta T})]Q'(\bar{p})$$

Since marginal cost will always exceed marginal cost when the ceiling binds, this term is positive, and so as the price cap falls, so too does the cycle length. ∎

# ENDNOTES

1 - Construction of oil and natural gas pipelines also constitute discrete jumps in capacity. Telecommunications examples include fiber optic cable strung across an ocean or a satellite placed in geo-stationary orbit for microwave relay.

2 - Several authors have extended the Averch-Johnson (1962) model of rate-of-return regulation to a dynamic setting. El-Hodiri and Takayama (1981) explicitly incorporate convex adjustment costs of investment with everywhere *decreasing* returns to scale construction. Dechert (1984) allows for increasing returns in production but not in plant construction. Both find that, with some qualifications, the Averch-Johnson results bear up over the longer run. My analysis appears to be the first to treat the case of construction economies.

3 - A price cap scheme was part of a larger program of incentive regulation proposed to the Federal Energy Regulatory Commission by Brown, Einhorn and Vogelsang (1989).

4 - To see this note that $dA/dT = [(dI/dT)\delta T-\delta I]/(\delta T)^2$. Substituting $dI/dT = \delta e^{-\delta T}K$, yields $dA/dT = [\delta^2 e^{-\delta T}KT - \delta(1-e^{-\delta T})K]/(\delta T)^2$. This last expression is negative since $1-e^{-\delta T}-\delta Te^{-\delta T}$ can be shown to be positive.

5 - Note that a lump of size I made at the end of a cycle of length T will cost $C((1 - e^{-\delta T})K)$; the firm's rate-base would then jump by exactly: $C(K) - C(Ke^{-\delta T}) < C((1 - e^{-\delta T})K)$. In words, the project may increase the rate base by an amount higher or lower than its stand-alone cost. The reason is that the unit "price" of capital varies with the size of the project. This inequality arises in spite of the use of Hotelling depreciation.

6 - If not, then a more realistic description of rate-of-return regulation would have the firm satisfy the constraint on average over a period of time. My suspicion is that the standard Averch-Johnson results would continue to hold.

7 - Without restrictions on $\hat{K}(\cdot)$ and $\hat{T}(\cdot)$, it can happen that the rate-of-return constraint binds from the very beginning of the cycle (i.e., $Ke^{-\delta T} > k_\ell$) or through to the end (i.e., $K < k_u$).

8 - In a steady state, if the composition of capital stock is checked immediately before another lump is added, then the fraction made up of the vintage installed n cycles earlier is $(e^{\delta T}-1)e^{-\delta nT}$. Differentiation by T shows that the proportion of the most recent vintage rises with cycle length while all others fall.

9 - In a lumpy investment model, Rees (1986) examined the effect of a price ceiling applied to the second-best price-investment plan. In his model, perfectly durable lumps of a predetermined size are added to meet growing demand. In addition, his short-run technology had a capacity constraint that made non-price rationing necessary. Rationing costs were instrumental to his result that investment cycle shrinks when a budget constraint binds.

10 - Boiteux (1949, p. 176), italics in original. Park (1989) carried Boiteux desire for price stability to an extreme, prescribing *constant* prices in a model of lumpy capital expansion. Using simulation methods, he finds that Boiteux's prescription deviated little in performance from the optimal constant price. However, permitting prices to freely vary over time registered large gains in social welfare over either sort of constant price.

11 - Several policies are described and analyzed in Perl (1985) and by the other contributors to a symposium issue of Resources & Energy.

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FIGURE 1

Steady-State Price and Investment Cycles

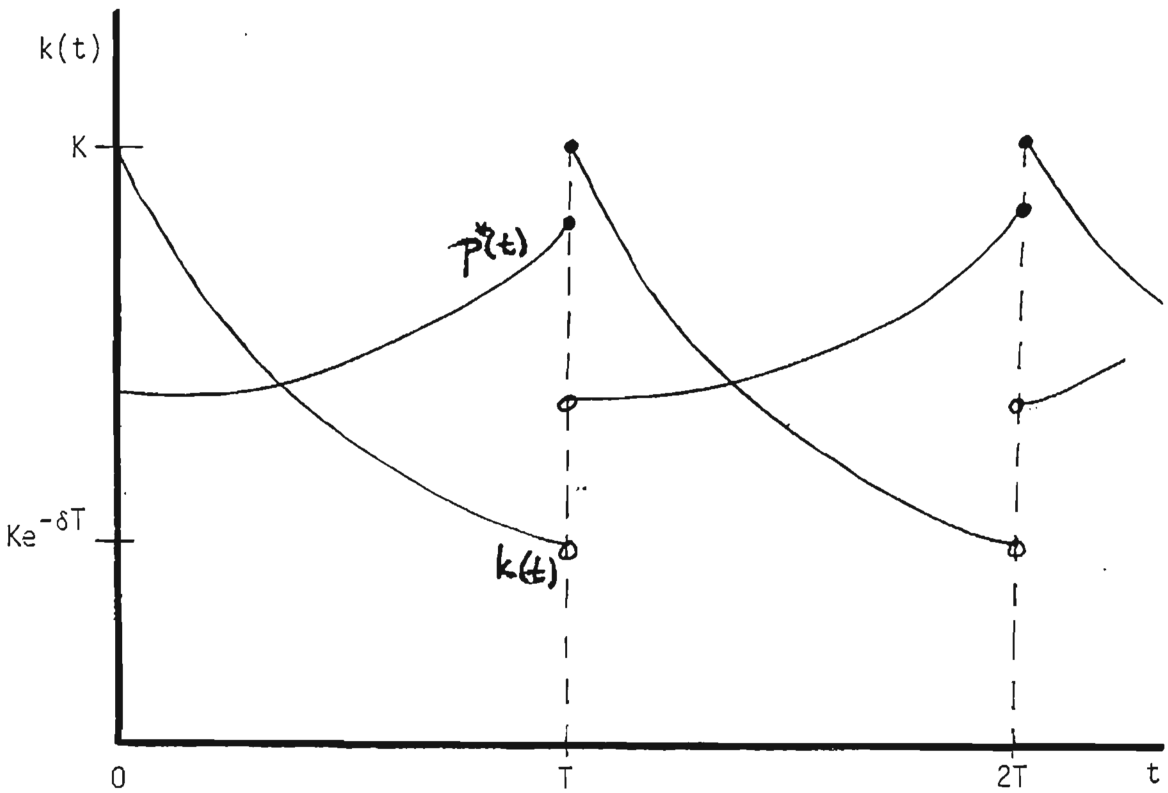

FIGURE 2

Monopoly Quasi-Rent and the Rate-of-Return Constraint

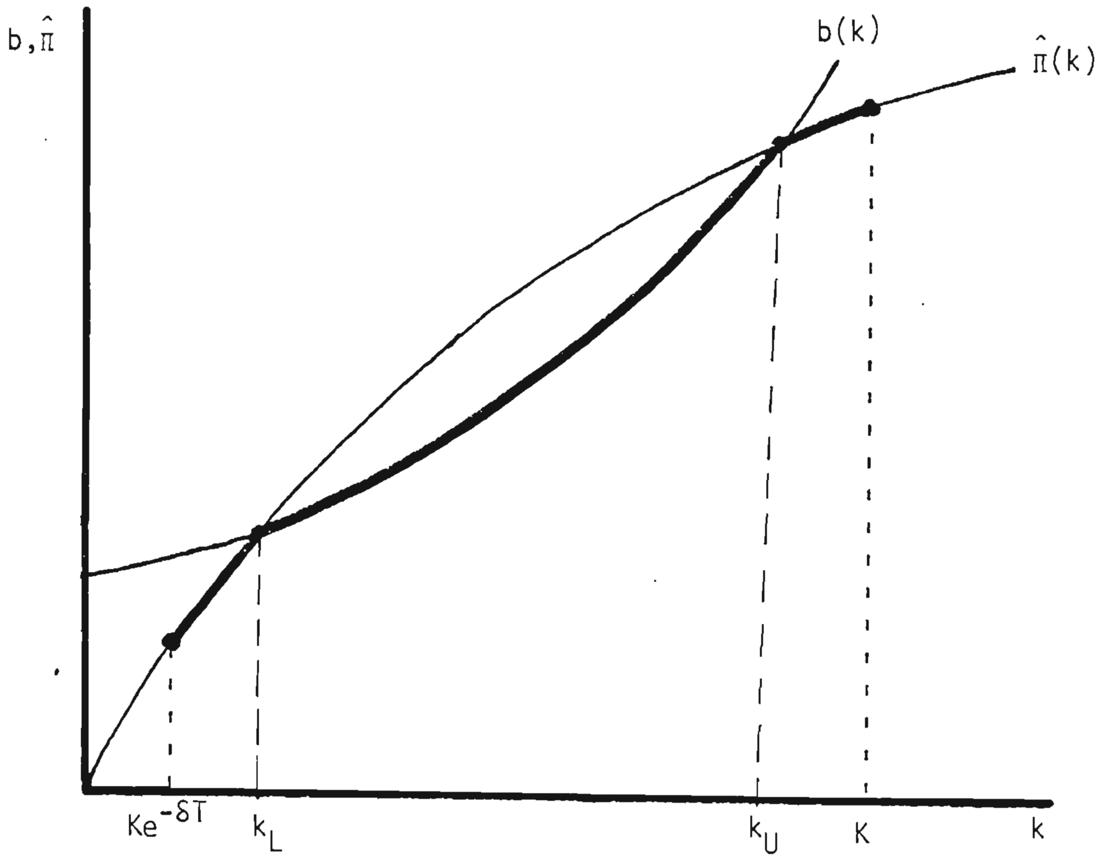

FIGURE 3

Effects of Rate-Base Regulation

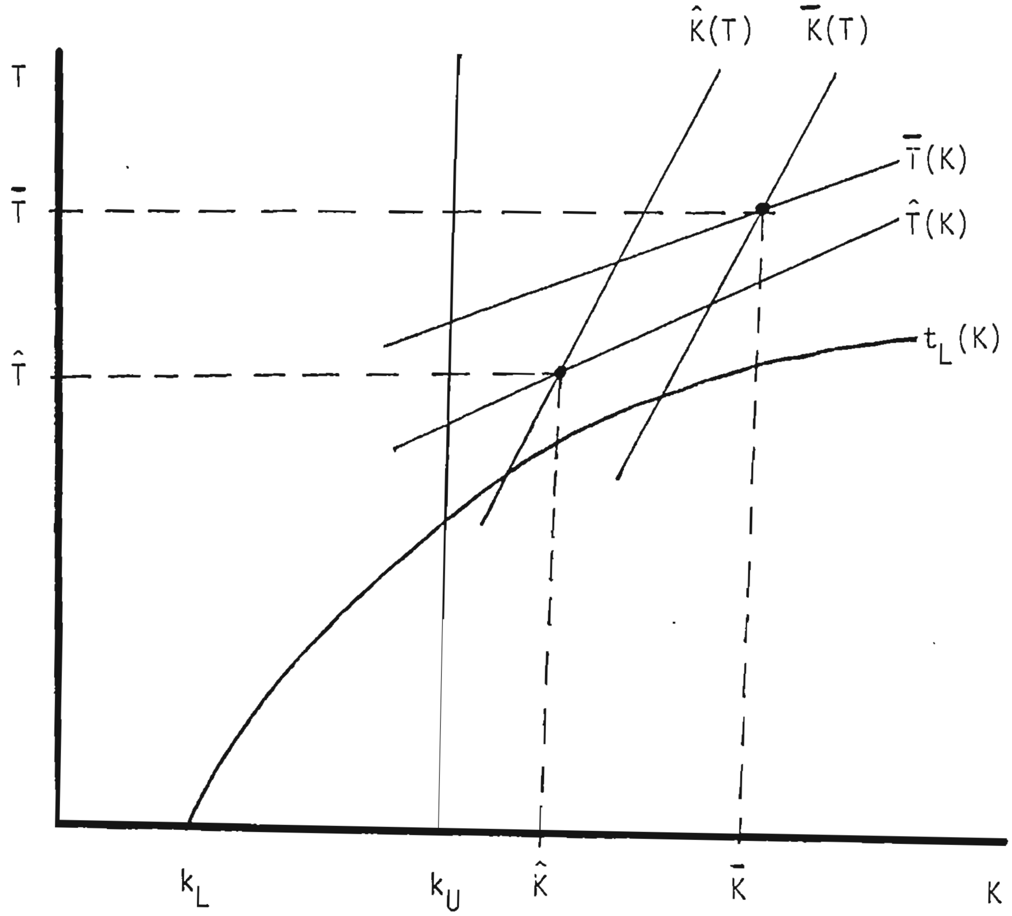

FIGURE 4

Prices Constrained by a Fixed Ceiling