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ABSTRACT

This paper proposes a new theoretical model for a stochastic regulation mechanism to set prices charged by public utilities. The objective function for the regulator has triple goals of keeping profits close to a regulated level, low variance of prices and low level of prices. An explicit price setting rule is obtained by using Wiener-Hopf arguments due to Whittle. Actual profits, regulated profits, and the price of output are allowed to have stochastic components. An empirical implementation based on Bell System time series data suggests no reward for productivity improvements, and a strong desire for low and stable rates.

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1. Introduction

Market failure theory of regulation states that the governmentmay intervene to help attain optimum welfare by providing "public goods", by exploiting economies of scale, externalites, and similiar areas where market solution may fail to attain the optimum. A simple version of the theory states that the regulation is for the benefit of the consumers. The "capture" theory states that once the regulatory mechanism is established, it can be manipulated by the producers to their advantage, and its simple version states that regulation is aimed at "producer protection". Empirical tests of these two types of theories have generally found little support. Schwert(1977) calls the consumer protection or producer protection dichotomy to be "too simplistic", and suggests that a more sophisticated model of the regulatory process must be developed. This paper is an attempt to develop an eclectic model of the behavior of the regulators operating in a stochastic setting and having multiple objectives. The objective function of the regulators proposed here has one component for consumer protection modeled as the desire to keep the price level to be low, the producer protection component is modeled in terms of deviations from a "fair" or "allowed" rate of return, which defines the minimum earnings of the producer. A desire on the part of regulators to keep the status quo, or "Don't rock the boat" by not allowing the prices to fluctuate too much, was noted by Peltzman(1976, p227) and Owen and Braeutigam(1978, p25). It is modeled here by including the variance of prices as an additional component in the objective function.

When the inflationary pressures hit the regulated industries in the 1970's the producer protection was often thought to be needed, because it was feared that the delays of the regulatory process may cause some producers to go bankrupt, or unable to raise capital, ultimately resulting in a loss of service to the consumers. It was recognized that both producers and consumers had to be protected, and specific suggestions to improve the process of regulation were made. For example, Isaac(1982), Lindsey(1977), Ram Mohan, et.al(1977) have studied the fuel adjustmentclauses, whereas Sudit(1979) is concerned with providing incentives for improving the total factor productivity. The idea is to exploit the self interest of the producers in such a way that they are encouraged to provide consumer protection. The eclectic model of regulation proposed here considers these incentive schemes by appropriately adjusting the computation of "fair" rates of return. We will show that our theoretical model of regulation can be readily extended to include the incentive schemes.

In the literature dealing with Averch and Johnson(1962) the focus of attention is on the behavior of the firm, not of the regulators. Section 2 describes our model of the firm behavior, where we are unable to evaluate the choice of inputs by the firm, but it involves dynamic optimization over an infinite horizon following Sargent(1979, ch.15). The regulators are confronted with the problem of satisfying the consumer interests, producer interests, and achieving stability of prices. These are formulated as triple objectives and described in Section 2. An analytical solution to the regulator's problem is given in Section 3. The main work horses for obtaining solution to our eclectic model of regulatory behavior are certain results from Wiener and Hopf described in Whittle's 1963 monograph, recently reissued as Whittle(1983), and results in Sargent(1979). Some modifications to these results are needed to make them applicable to the regulatory behavior, and are discussed in an Appendix. The solution to the regulator's optimization problem may be viewed as a normative result for certain purposes, if the relative weights on the three components of the objective function are known.

Section 4 discusses empirical implications of our eclectic theory of regulatory behavior, where the relative weights on the three components of the objective function are inferred from the historical behavior of the regulator and the business firm. Their respective decision rules based on analytical results give rise to two behavioral equations, which are simultaneously estimated. If we can assume that the relative weights remain constant throughout the historical period covered, we can immediately estimate the relative weights on the three components. Since the makeup of the regulatory entity changes over time, the assumption of fixed relative weights may not be realistic. Section 4.1 proposes a Kalman filter technique to estimate the changing weights. Section 5 discusses an empirical application to Bell System data, and reports the changing relative weights over 1951 to 1980 time period. Since we have drastically simplified the firm's behavior, it is useful to check whether the fit is good. In our case, the multiple correlation (R^2 =0.8966) is reasonable, and the results regarding the interpretation of the relative weights at various times are also sensible in light of generally known changing circumstances of the Bell System. We conclude in Section 6 that the results are encouraging for the more realistic eclectic theory of regulatory behavior, which avoids the dichotomy of consumer or producer protection.

2. Profit Maximization in a dynamic model of the regulated Firm

Since this paper is concerned with the optimization by the regulator we drastically simplify the stochastic optimization by the firm. For example, we do not seek to determine the input levels of capital, labor, etc. We indicate, but not derive, the decision rule under a quadratic objective (see Sargent (1979) p. 333). The (discounted present) value of the firm is maximized by maximizing:

$$v_t = E_t \sum_{j=0}^{\infty} b^j \; g\,(R_{t+j-1}, R_{t+j}, S_{t+j}) \qquad (2.1)$$

over the stochastic process for the rate of return (net revenues per unit of relevant capital stock) denoted by R_{t+j} for j = 0 to ∞ subject to given value of R_{t-1}. Here g is a concave (quadratic) function in R_t which contains a term in $(R_t - R_{t-1})^2$, and S_t is a vector of random variables exogenous to the firm, b < 1 is a discount factor, E_t is the expectation operator based on information available at time t. The firm can devise a recursive strategy for future values R_{t+1}, R_{t+2}, etc. depending on future information, (e.g., future course of regulation). Its simplified problem at time t is to maximize the rate of return R_t by reducing costs, by properly allocating the inputs and outputs, etc.

Sargent's (1979) solution is recursive, involving stochastic Euler equations and transversality conditions. We exploit the fact that Sargent's decision rule for the firm is linear:

$$R_t = \lambda_1 R_{t-1} - \lambda_2 \sum_{i=0}^{\infty} \lambda_2^{-i} \; E_t \, S_{t+i} \qquad (2.2)$$

involving conditional expectations of exogenous variables and coefficients in g, Sargent (1979, p. 336). This is a generalization of a perfect foresight model to allow for random variables.

We assume that the firm is a price taker, making p_t, the price of the output at time t as belonging to the set S_t of exogenous variables in (2.2). The gross revenues will obviously be affected by demand shocks, and the performance of the firm is judged by its costs, efficiency, quality of service, etc. We assume that if R_t, the actual rate of return earned (scaled net revenue), is inappropriate the regulator can order a change in prices p_t. Recent regulatory economics literature suggests that there are other variables often considered by the regulator, including TFP_t (total factor productivity, Kendrick(1961), which is a ratio of sales to cost of all inputs evaluated at base year prices), $FUEL_t$ (fuel cost adjustment), π^*_t (the "fair" or "allowed rate of return" previously announced by the regulator). Direct inclusion of all such variables in S_t of (2.2) is conceptually straightforward, but mathematically tedious. We simplify matters by incorporating the effect of π^*_t indirectly via R_{t-1} and p_t, and redefine the firm's decision variable to be $\pi_t = R_t - f(TFP_t, FUEL_t)$, where a function f is made "deductible" by the regulator as explained below. Note that the inclusion of $f(TFP_t, FUEL_t)$ is a refinement to inject realism, and is by no means essential for the logic of our model. From the regulator's viewpoint, the weights in the firm's quadratic objective function (λ_1 and λ_2) and the conditional expectations (E_t) are unknown. However, the regulator can estimate an empirical relation similar to (2.2) by adding an error term.

3. A Solution to Regulator's Problem

From the viewpoint of the regulator, the threefold objective is to obtain optimal improvements in productivity so that; (i) the rates of return (scaled profits) of the regulated firm are "close" to the pre-specified regulated values, (ii) output prices do not fluctuate too much, and (iii) output prices are not too high on an average. The producer protection version of the "capture" theory of regulation is only partially included by the presence of the first term. The regulator's own desire for "calm waters" is approximated by the second term. It is an implication of at least two recent studies: (a)

Peltzman's(1976) theory of regulation based on an elegant model of the regulator as a rational politician who wishes to maximize his votes through income redistribution, and (b) Owen and Braeutigam(1978) argument that voters favor "procedural fairness" of a judicial process, which reduces the risks faced by individuals by delaying change in existing prices of existing services. The consumer protection version of public interest hypothesis is included in the third term. It is the presence of all three terms in the objective function that makes our model eclectic and more general than what is available in the economics literature. Since Whittle's solution used here does not permit arbitrary specification of the terms in either the objective function or the behavioral equation of the firm, equation (3.1) is not claimed to be the most general.

Now the regulator's objective function L based on (i), (ii) and (iii) above, may be written in terms of minimization of a mathematical expectation(E) defined as follows:

$$L = E[(\pi_t - \pi^*_t)^2 + \mu_1(p_t - \bar{p})^2 + 2\mu_2\bar{p}\ ] = V_R + \mu_1 V_p + 2\mu_2\bar{p} \quad (3.1)$$

which defines average squared deviations V_R and V_p, and where [1, $\mu_1 > 0$ and $\mu_2 \geq 0$] are coefficients representing known relative weights on the three terms. We assume that regulators have the power to change them and to keep their future values secret. This power can be used to counter some types of strategic (evasive) behavior by the firm. Note that π^*_t depends on macroeconomic environment, (interest rates, rates of return earned by other firms with equivalent risk characteristics, etc. exogenous to our model), and cannot be conveniently determined in terms of the regulator's decision rule. However, its importance (weight) can be changed by paying more or less attention to the discrepancy $|\pi_t - \pi^*_t|$. The mutually comparable relative contributions of the three terms to the loss L, even with unknown μ_1 and μ_2, are measured by the three partial derivatives of L with respect to the natural logs of V_R, V_p and $\bar{p}$ respectively. We have the relative weights:

$$[V_R,\ V_p(\mu_1),\ \text{and}\ \bar{p}(2\mu_2)], \quad (3.1a)$$

measuring the effect of a one (say) percent change in the three terms on the loss L of the regulator defined in (3.1). The three weights in (3.1a) are free from units of measurement, and obviously represent relative importance of (i) some aspects of producer protection (ii) "Don't rock the boat" motive, and (iii) consumer protection motive. This assumes that μ_1 and μ_2 in (3.1a) minimize L, with L providing a complete specification of what is important to the regulator. We will see that it is possible to measure (3.1a) empirically.

For simplicity of exposition we write (2.2) as

$$\pi_t = b_1 + b_2 p_t + b_3 \pi_{t-1} + \varepsilon_t \qquad (3.2)$$

where

$$\pi_t = R_t - b_4 \, TFP_t - b_5 \, FUEL_t \qquad (3.3)$$

That is, we have netted out the effect of TFP_t and $FUEL_t$. This amounts to designating a certain proportion of "productivity" and cost increases "deductible" before the rate of return is compared with the "allowed" rate of return. Wasted FUEL input is discouraged by the regulator by making $b_5 < 1$.

The idea behind automatic deductibility of TFP_t and $FUEL_t$ is exactly the same as with many of the income tax laws. It can encourage increases in TFP, and achieve fairness by not penalizing the utility company for cost increases outside its control. This device allows for a richer behavioral model of the firm without complicating the mathematics. Of course, if the main interest is to numerically minimize multiple objectives similar to (3.1) subject to (3.2) one may use Linear Quadratic Gaussian (LQG) Regulation developed by Kalman and others. Sargent's foreword to Whittle's second edition notes the advantage of Whittle's methods for "deducing closed form solutions for decision rules". Chow (1983) illustrates some special cases where LQG methods can yield "explicit" solutions.

The technical derivation is given in an Appendix. If one wishes to use LQG methods for our problem the stationary problem solved in Section A.1 of the Appendix will be replaced. However, it is unlikely that the numerical solution will be much different. The presence of the third term in (3.1) means that appropriate modifications to the LQG solution will be needed, similar to those of Section A.2 of the Appendix. The solution from equation (42) of the Appendix is:

$$p_t = \bar{p} + C_1 (\pi_{t-1} - \bar{\pi}) + C_2 (\pi^*_t - \bar{\pi}^*) \qquad (3.4)$$

where

$$C_1 = (\xi - b_3)/b_2 \quad \text{and} \quad C_2 = (K^2 b_2)^{-1} \qquad (3.5)$$

and where

$$\xi = (A/2) + (1/2) (A^2 - 4)^{1/2} \qquad (3.6)$$

$$A = b_3 + (1/b_3) + (b_2^2 / \mu_1 b_3) \qquad (3.7)$$

$$K^2 = \mu_1 b_3 / (\xi \ b_2^2) \qquad (3.8)$$

and where the bars indicate mean values. A derivation of this solution is claimed to be one of the contributions of this paper.

A regulator can use this solution to determine the appropriate price levels for the regulated products or services if relative weights μ_1 and μ_2 are known. As a practical matter, the regulator may wish to know historical values of μ_1 and μ_2, and may wish to change them. An interesting possibility is to use this solution for ex post policy evaluation, by the regulator or by any researcher. Assuming that the regulators are minimizing (3.1) we can estimate the relative weights (3.1a) as derived in the following Section.

4. Derivation of Empirically Estimable Weights

Econometricians often use normative optimizing solutions like (2.2) and (3.4) as behavioral equations, even though the agents cannot be expected to succeed in optimizing at all times. We assume that agents do not deviate from optimizing solutions in a systematic way, and use random normal errors to approximate all errors in optimizing equations.

For empirical work then, we can estimate b_1 to b_5, C_1 and C_2 in the following set of three equations:

$$\pi_t = b_1 + b_2 p_t + b_3 \pi_{t-1} + u_{1t}, \qquad (4.1)$$

$$(p_t - \bar{p}) = C_1 (\pi_{t-1} - \bar{\pi}) + C_2 (\pi^*_t - \bar{\pi}^*) + u_{2t}, \qquad (4.2)$$

where the prespecified π^*_t is exogenous, (not emanating from regulator's decision rule, but subject to macroeconomic environment), u_{1t} and u_{2t} are the error terms, and where we also have a definitional identity:

$$\pi_t = R_t - b_4\ TFP_t - b_5\ FUEL_t. \qquad (4.3)$$

These equations represent the empirical counterpart of the optimizing behavior of firms and regulators.

Using equations (3.4) to (3.8) and (37) of the Appendix it can be verified by eliminating ξ, K^2, and other manipulations that the weights of (3.1a) can be written in terms of b_1 to b_5, C_1 and C_2. A main result of this paper is our specification of (4.1) to (4.3) which facilitates the following connection between theory and estimables. We have:

$$V_p\mu_1 = V_p b_2\ (C_1 b_2 + b_3)/C_2 b_3\ , \qquad (4.4)$$

$$2\bar{p}\ \mu_2 = 2\bar{p}(\bar{\pi}^* - \bar{\pi})/C_1\ . \qquad (4.5)$$

The econometric identifiability of these weights is obvious thanks to the nonlinearity of (4.4) and (4.5). However, usual standard errors of nonlinear functions (involving reciprocals) of normal variables are known to be unreliable in small samples, and it may be necessary to use sophisticated bootstrap or jacknife resampling methods. The choice between them remains controversial, and left for future research. If the units of measurement of prices p_t are changed to c^*p_t it can be verified that (4.4) and (4.5) remain unchanged. For example, C_1 becomes c^*C_1 and $\bar{p}$ becomes $c^*\bar{p}$ keeping (4.5) unchanged. Similarly, when (π_t, π^*_t) are both multiplied by an arbitrary constant d^*, all elements of (3.1a) get multiplied by d^{*2}, keeping the relative magnitudes unchanged. We claim that the estimated (3.1a) weights yield useful information about regulatory behavior, if the loss function is reasonable.

A maximum likelihood estimation of these relative weights is clearly feasible. For example, under normality and independence of u_{1t} and u_{2t} we may simply minimize:

$$\sum_{t=1}^{T} (u_{1t}^2 + u_{2t}^2)$$

to estimate b_1 to b_5, C_1 and C_2, eliminating (4.3) as a separate equation. The starting values for the non-linear maximum likelihood estimator may be based on ordinary least squares estimates of (4.2) and a non-linear least squares estimate of:

$$R_t = b_1 + b_2 p_t + b_3 R_{t-1} + b_4 (TFP_t - b_3 TFP_{t-1}) + b_5 (FUEL_t - b_3 FUEL_{t-1}) \qquad (4.6)$$

based on (4.1) and (4.3). In some specifications b_4 and/or b_5 may be zero, and will simplify initial estimation. In any case, one can use standard econometric tools to estimate all the parameters of the proposed theory. Thus, it is possible to measure the relative weights in (3.1a) associated with "Don't rock the boat" and other objectives. A comparative study of such weights across industries would be interesting. In the following subsection we propose a comparative study of these weights over time.

4.1 Time Varying Estimates of Relative Weights by Kalman Filter

This subsection discusses the special case when the overall estimates of μ_1 and μ_2 obtained above are found to be inadequate in a particular regulatory situation. For example, if the members of regulatory panels often change or the views of the panelists change due to political or other influences, then we may need "time varying parameter" or "random coefficient" models surveyed in Vinod and Ullah (1981, sec. 10.4) or Chow (1983, Ch. 10).

We suggest using the standard Kalman filtering method, elegantly expounded in Whittle (1983, p.147), to find the time varying estimates of all parameters b_1 to b_5, C_1 and C_2, provided enough data points are available. These estimates can then be used in conjunction with b_1 to b_5 to substitute in (4.4) and (4.5) to obtain the relative weights of "Don't rock the boat" and other components as it changes over time. It is convenient to assume that the basic motivations and behavior of the firm does not change over time, and concentrate on the varying parameter estimation of C_1 and C_2 only to conserve the degrees of freedom and to keep the computational burden manageable. We will now briefly describe the Kalman filter used here, since its application in regulatory context appears to be new. For this subsection we use Chow's notation appropriately simplified for our application, because he has also outlined the general case where all parameters are varying with time; and the reader may be interested in pursuing the general case. For each t we have:

$$y_t = x_t\beta_t + \varepsilon_t, \qquad \varepsilon_t \sim N(0,\sigma^2) \tag{4.7}$$

and

$$\beta_t = \beta_{t-1} + \eta_t, \qquad \eta_t \sim N(0, V) \tag{4.8}$$

model describing the changes in β over time. In our case β_t is a 2x1 vector with elements C_1 and C_2 both at time t, x_t is a 1x2 vector of regressors in (4.2) and y_t is the dependent variable $(p_t - \bar{p})$, and u_{1t} has been renamed ε_t in this subsection.

The first step is to find initial estimates of σ^2 and the covariance matrix V of C_1 and C_2. These are conveniently obtained from overall estimates (i.e. not varying with t) in the previous Section by any one of the econometric estimation methods. The covariance matrix of β_t conditional on all past values of y_t is denoted by $\Sigma_{t|t-1}$ and obtained by

$$\Sigma_{t|t-1} = \Sigma_{t-1|t-1} + V , \tag{4.9}$$

which are (2x2) matrices in our case. To start using (4.9) we need $\Sigma_{0|0}$ which could be the null matrix. The next step is to get

$$\Sigma_{t|t} = \Sigma_{t|t-1} - \Sigma_{t|t-1}\, x'_t\, [x_t\, \Sigma_{t|t-1}\, x'_t + \sigma^2]^{-1}\, x_t \Sigma_{t|t-1}, \tag{4.10}$$

where x_t is a row vector of two elements in our case.

The next step is to get Kalman weights on residuals

$$K_t = \Sigma_{t|t-1}\, x'_t\, [\, x_t\, \Sigma_{t|t-1}\, x'_t + \sigma^2\,]^{-1} \tag{4.11}$$

to substitute in the second term on the right side of:

$$\beta_{t|t} = \beta_{t|t-1} + K_t (y_t - x_t \beta_{t|t-1}), \tag{4.12}$$

where we can use $\beta_{t|t-1} = \beta_{t-1|t-1}$ based on the fact that we have a simple model for (4.8). Starting with initial estimates of C_1 and C_2 as elements of our $\beta_{o|o}$ vector (4.12) can yield the values of C_1 and C_2 at t=1, 2,...,T for substitution in (4.4) and (4.5) to assess the relative weight on "Don't Rock the boat" and other objectives.

Our inequality constraints are $\mu_{1t} > 0$ and $\mu_{2t} \geq 0$. The negative values for μ_{2t} may be replaced by zeroes. The negative or zero values for μ_{1t} may require further study and a possible use of the negative root in ξ of (26a) of the Appendix. Thus one can find the relative weights in (3.1a), given by the regulators as functions of μ_{1t}, μ_{2t}, defined here for each t. These can be studied (plotted) for assessmentof the changing regulatory climate. Any one of the several varying parameter models from the literature may be used. The Kalman filter recursive model described here is illustrated in the following Section.

5. Empirical Implementation

The purpose of this Section is to demonstrate the practical feasibility of our proposal, and instill life into our formulas with the help of a numerical illustration. We use certain pre-divestiture Bell System data for 1950 to 1980. Aggregative prices (p_t) are based on an implicit price deflator for the total operating revenues of the Bell System. Return on (average) total capital R_t actually earned is obtained from the Bell Syatem statistical summaries. The "allowed" (or "fair") rate of return π^*_t series is constructed from information about dates on which new interstate rates of return became effective in accordance with a formal action by the Federal Communications Commission (FCC), or the U.S. Congress. The rate of return allowed by the State Public Service Commissions (PSC's) is usually 1 or 2 points smaller. An aggregative weighted index from information about dates and returns allowed by PSC's is not feasible, especially for years before 1970. The data on total factor productivity (TFP) were kindly made available by the Economic Analysis Section of AT&T. The $FUEL_t$ variable was not judged to be important for this application.

Nonlinear two stage least squares estimates of the parameters of the model in (4.6) with $b_5 = 0$ are:

$$\pi_t = -1.963 + 6.301\, p_t + 0.554\, \pi_{t-1}$$
$$(-1.48) \quad (2.73) \qquad (3.32)$$

$$-0.0275\, [TFP_t - 0.554\, TFP_{t-1}] \qquad (5.1)$$
$$(-1.06) \qquad (3.32)$$

with $R^2 = 0.8966$ adjusted for degrees of freedom and where the numbers in parentheses are Student's t values. An interesting point to note is the negative coefficient b_4 with a low t value. This tends to suggest that the regulators did not give any incentive to the telephone companies for any increase in TFP, and may even have penalized them for it. Hence we choose an alternative specification having $b_4 = 0 = b_5$ in (4.3), which simplifies the model to a system of two linear equations (4.1) and (4.2) with $\pi_t = R_t$.

A full information maximum likelihood (FIML) estimation of (4.1) and (4.2) for Bell System data is as follows. Using the SORITEC computer package the convergence was achieved after eleven iterations and twenty one evaluations of the likelihood function. We have the following coefficient estimates and t values: $b_1 = -0.330$ (-.994), $b_2 = 3.644$ (6.420), $b_3 = 0.544$ (6.373), $C_1 = 0.0268$ (1.239) and $C_2 = 0.0893$ (5.263). Using these estimates in (4.4), and (4.5) we have $\mu = 48$ and $2\mu_2 = 7$. Also, we have $\bar{\pi}^* = 7.73$, $\bar{\pi} = 7.62$, $\bar{p} = 1.06$, $V_p = 0.0214$, $V_R = 0.1810$. Further empirical details and data are available upon request.

The relative weights (0.18, 1.03 and 8.35) based on (3.1a) and given to the terms involving $(\pi_t - \pi^*_t)^2$, $(p_t - \bar{p})^2$ and $\bar{p}$ in the loss function (3.1) represent an <u>ex post</u> view of the empirical data for the Bell System companies, as they were regulated during the 1951 to 1980 pre-divestiture period. The regulators seem to give greatest importance to the price level (consumer protection), lesser importance to price stability (don't rock the boat), and the least importance to keeping close to the "allowed" rate of return. This conclusion persists for alternative specifications (non-linear case) and estimation methods (two or three stage least squares, etc.). The low weight on the first term seems to support Kahn's(1970, p42) view that "There is no single scientifically correct rate of return, but a 'zone of reasonableness' within which judgmentmust be exercised".

Averch and Johnson (AJ, 1962) prove their famous distortion effects arising from rate of return regulation analytically, not empirically. Static Bell data production function studies such as Vinod(1972) found no evidence of distortion in favor of the capital input. The present study casts doubt on the realism of AJ's implicit assumption -- that the regulators try to make π_t very close to π^*_t -- to the Bell data, because the first weight in (3.1a) is empirically estimated to be low. Of course, our model cannot rule out input choice distortions.

Table 1 reports changing annual values of relative weights from (3.1a), which in turn are functions of μ_{1t} and μ_{2t} based on Kalman filtering described in Section 4.1. Since μ_{1t} and $2\mu_{2t}$ are relative quantities it is obvious that the weight of the first term does not change with time. Note that the weights in the last column remain high, except for the zeroes in 1955 and 1963 to 1970. The zero in 1955 follows large values for 1952 to 1954 attributed to the Korean war boom and inflation. The zero values for $2\bar{p}\ \mu_{2t}$ appear in years when telephone prices were not inflationary, and even falling in some cases. The allowed rate of return π^*_t for 1970 was 8.25 which was a major jump from the 1969 value of 7.41. This may help explain the jump in 1971 from 0 to 32.10 in the last column of Table 1.

The relative weights for "Don't rock the boat" are somewhat high during 1957 to 1960 and in 1972 to 1975. Note that 1972-75 was the time when there were telephone "service" problems, and many areas were suffering from unacceptable dial tone delays. In response to these problems New York Telephone alone invested over a billion dollars per year, and asked for rate increases to pay for the increased investment. Similar changes occurred in other parts of the Bell System, and may have resulted in greater attention to the variance of prices by the telephone regulators. Although the constraint $\mu_{1t} > 0$ is not violated, and the results seem to make sense, their interpretation is not claimed to be definitive.

6. Conclusions

Multiple regulatory objectives include ensuring that the (1) rate of return earned equals the "fair" rate (2) prices are stable (3) prices are low (4) productivity is high (5) there is no unfair penalty for input (FUEL) price inflation, and no incentive to waste such inputs. The realization that they are relevant is not new in the regulatory economics literature, although a unified framework for simultaneously including them in an empirically manageable loss function seems to be missing. This paper provides a unified framework by using Wiener-Hopf-Whittle stochastic optimization to provide a new pricing rule (3.4), whose derivation may be of interest in other fields. Our regulators can accomplish all objectives above, simultaneously and with varying weights, within the framework of our simplified model.

The first objective above is viewed in terms of some aspects of the "capture" theory of regulation, if it is assumed that the fair rate protects the producer from potential bankruptcy, and keeps competition out. The second objective is viewed in terms of "Don't rock the boat" motive on the part of regulators. Peltzman(1976), Owen and Braeutigam(1978) discuss models supporting the notion that regulators avoid price fluctuations. The third objective of keeping prices low is obviously for consumer protection, and its failure protects the producer. We are not locked into accepting only one objective, such as the producer protection hypothesis of the capture theory. Our theory of regulation is potentially useful because it can include all five objectives in an empirically manageable loss function. We propose replacing the current theories of regulation, which are already regarded in the literature as being "too simplistic", by a more general model based on our eclectic theory. Some of the existing theories can be shown to be special cases, and the empirically estimated relative weights can help decide which theory is (heuristically) more relevant in which industry.

An important limitation of the proposed model is that we have drastically simplified the firm's behavior. Our linear recursive representation, based on Sargent's (1979) model proposed in a different context, may not adequately include strategic (evasive) behavior. Another limitation is that our "varying parameter" estimation based on Kalman filtering does not allow varying parameters in the behavior of the firm. However, we do not necessarily recommend generalizing this aspect if the number of data points is small. Finally our reliance on a quadratic objective function may be unrealistic in some cases. More research is needed to devise appropriate small sample confidence intervals by comparing normal theory, bootstrap and jacknife for the empirical weights which are nonlinear functions of parameters estimated by complicated (e.g. Kalman filter) methods.

Empirical checking of the model for the first four objectives listed above is made with the help of Bell System data. Generally largest weight on the third objective (consumer protection) suggests that the regulators consider a one (say) percent change in average price level most seriously. Relatively low weight on the first objective (in conjunction with the large weight on the third) provides little support for the allegation that telephone regulators are "captives" of the industry, and suggests that the Averch-Johnson assumption of strict adherence to an exogenously fixed rate of return may not be realistic for telecommunications. A desire to keep telephone rates stable is indicated by a generally larger weight on the second objective than on the first. Hence our results suggest support for the "Don't rock the boat" motivation hypothesis implicit in Peltzman, Owen, Braeutigam and others. We find no evidence of any direct productivity incentives having been granted to the telephone companies during the pre-divestiture period. The numerical illustration shows the practical feasibility of the model, despite somewhat complicated derivation of the implications of the loss functions.

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TABLE 1 Relative Weights on Price Variance and Price Level: Approximate Annual Values

	$V_p \mu_{1t}$	$2\bar{p}\ \mu_{2t}$
1951	1.00	8.89
1952	0.97	10.52
1953	0.89	18.43
1954	0.84	43.57
1955	0.81	0
1956	1.13	13.14
1957	1.57	6.88
1958	1.54	7.70
1959	1.78	5.90
1960	1.41	8.68
1961	1.09	21.23
1962	1.01	32.97
1963	0.68	0
1964	0.63	0
1965	0.51	0
1966	0.40	0
1967	0.38	0
1968	0.38	0
1969	0.36	0
1970	0.71	0
1971	1.13	32.10
1972	1.25	17.95
1973	1.35	14.03
1974	1.37	9.64
1975	1.52	4.89
1976	0.88	15.39
1977	0.84	12.39
1978	0.98	6.20
1979	1.04	5.32
1980	1.03	5.40

Note: See equation (3.1a). Column $V_p \mu_{1t}$ gives the relative weight on "Don't Rock the Boat" motive and column $2\bar{p}\mu_{2t}$ gives the weight on consumer protection motive. Relative weight on producer protection (capture theory) is maintained at $0.18 = V_R$ by our (Whittle) model.

Appendix

We derive the solution to the optimization problem in the text using Wiener Hopf methods based on Whittle's (1963, Ch. 10) derivations and retain many of his notations. The regulated firm follows the decision rule:

$$\pi_t = f(p_{t-j}, \pi_{t-1-j} \text{ where } j = o, 1, \ldots) \tag{1}$$

as seen by the regulator. The regulator's objective function is

$$L = E\left[(\pi_t - \pi_t^*)^2 + \mu_1 (p_t - \bar{p})^2 + 2\mu_2 \bar{p}\right] \tag{2}$$

A simplified (1) is

$$\pi_t = b_1 + b_2 p_t + b_3 \pi_{t-1} \tag{3}$$

First we consider the non-stationary character of π_t, π_t^* and p_t by defining their stochastic stationary parts by

$$y_t = \pi_t - \bar{\pi}, \tag{4}$$

$$u_t = \pi_t^* - \bar{\pi}^*, \tag{5}$$

$$x_t = p_t - \bar{p}. \tag{6}$$

Since the optimization is over the entire trajectory, we need the specialized mathematical tools used here.

The expectations satisfy

$$E(y_t) = E(u_t) = E(x_t) = E\ (\varepsilon_t) = 0 \tag{7}$$

Taking expectation of both sides of (3) gives

$$\bar{\pi} = b_1 + b_2\bar{p} + b_3\bar{\pi} \tag{8}$$

We rewrite the objective function (2) as

$$L = E\left[(y_t - u_t)^2 + (\bar{\pi}^* - \bar{\pi})^2 + \mu_1 x_t^2 + 2\mu_2\bar{p},\right] \tag{9}$$

where the omitted cross product term will vanish upon taking its expectation.

The regulator's problem is to minimize (9) and determine an optimal decision rule for rates (prices) defined by

$$p_t = \beta^0 + \beta^{(1)}\ \pi_t + \beta^{(2)}\ \pi_t^* + \beta^{(3)}\bar{\pi}^*. \tag{10}$$

where β^0 is a constant, and for k=1,2,3

$$\beta^{(k)} = \sum_{j=0}^{\infty} \beta_j^{(k)} z^j. \tag{11}$$

defines the three operators. Note that $\beta^{(1)}$ may be specified with $\beta_0^{(1)} \equiv 0$ as a feedback of past profits on current prices. For a discrete time series in the time domain recall that we have used z as the a back-shift operator. In the frequency domain, $z = e^{-iw}$ with $i = (-1)^{\frac{1}{2}}$ is readily used.

From (10) we write the expectation of both sides as

$$\bar{p} = \beta^0 + \beta^{(1)}\bar{\pi} + (\beta^{(2)} + \beta^{(3)})\ \bar{\pi}^*. \tag{12}$$

Subtract (12) from (10) to give

$$x_t = \beta^{(1)}\ y_t + \beta^{(2)}u_t. \tag{13}$$

Subtract (8) from (3) to give

$$\alpha y_t = x_t + \varepsilon_t. \tag{14}$$

where $\alpha = (1-b_3 z)/b_2$ is also a polynomial in z.

These derivations will be useful in obtaining explicit solutions to the optimization of (9) in the following subsections.

A-1. Solution to the Stationary Problem

First we consider only two terms from the objective function (9) denoted by

$$V = E\left[(y_t - u_t)^2 + \mu_1 x_t^2\right] \tag{15}$$

representing a "stationary" portion of our problem. Let the spectral density function of the stochastic process u_t, $f_{uu}(w)$ be written as

$$f_{uu}(w) = g_{uu}(z) = \Psi_u(z)\ \Psi_u(z^{-1}) = |\Psi_u|^2 . \tag{16}$$

where g_{uu} is the autocovariance generating function. For example, if u_t is a white noise process $|\Psi_u|^2 = \sigma^2$ is a constant.

Substituting (13) in (14) we have

$$(\alpha - \beta^{(1)})\ y_t = \beta^{(2)}\ u_t + \varepsilon_t. \tag{17}$$

This may be written as

$$y_t = \theta(z)\ u_t + \phi(z)\ \varepsilon_t, \tag{18}$$

where the transfer function between y and u is defined by

$$\theta(z) = \sum_{j=0}^{\infty} \theta_j z^j = \frac{\beta^{(2)}}{\alpha - \beta^{(1)}} . \tag{19}$$

Similarly, the transfer function between y and ε is defined by

$$\phi(z) = \sum_{j=0}^{\infty} \phi_j z^j = \frac{1}{\alpha - \beta^{(1)}} . \tag{20}$$

Using Cauchy integrals and the residue theorem one can write the expectation in (15) as the absolute term (denoted by Abs) in a Laurent expansion on the unit circle $|z| = 1$. These methods are described in Nerlove et al. (1979) and Whittle (1963, pp. 118-126).

Using the factorization (16) we write the objective function as

$$V = \text{Abs}\left[|1 - \theta|^2|\Psi_u|^2 + \mu_1|\alpha\theta\Psi_u|^2\right]. \tag{21}$$

where the notation $|\beta|^2 = \beta(z)\,\beta(z^{-1})$ is used for brevity.

This V is minimized with respect to the coefficients θ_j, $j=1,\ldots,\infty$ by differentiating (21) with respect to θ_j. We have the first order conditions

$$\text{Abs}[z^{-j}H(z) + z^{j}H(z^{-1})] = 0, \tag{22}$$

where

$$H(z) = \left[(1 + \mu_1|\alpha|^2)\theta - 1\right] \Psi_u(z)\ \Psi_u(z^{-1}). \tag{23}$$

From (22) we know that coefficients of z^j in the Laurent expansion of $H(z)$ on $|z|=1$ are zero for all $j=1, 2 \ldots$. Hence powers $H_j z^j$ for $j = -\infty$ to 0 alone will remain non-zero in the expansion of $H(z)$.

We assume that our stationary series are convergent in some ring (annulus) containing the unit circle. Now we use the Wiener-Hopf method which involves retaining only the relevant powers of z^j from two equivalent expressions for $H(z)$. The solution is

$$\theta = \frac{1}{P(z)\Psi_u}\left[\frac{\Psi_u}{P(z^{-1})}\right]_0^{\infty}, \tag{24}$$

where the numbers outside the brackets indicate the range of powers of z retained, and where

$$|P|^2 = 1 + \mu_1(1-b_3z)(1-b_3z^{-1})b_2^{-2}. \tag{25}$$

The $P(z)$ and $P(z^{-1})$ for (25) are found by choosing a root (e.g. positive) of the quadratic function in z. The root is denoted by ξ, and we write

$$|P|^2 = K^2(1-\xi z)(1-\xi z^{-1}). \tag{26}$$

It can be verified that

$$\xi = (A/2) \pm \frac{1}{2}(A^2-4)^{\frac{1}{2}} \tag{26a}$$

where $A = b_3 + (1/b_3) + (b_2^2/\mu_1 b_3)$, and then we can find the remaining unknown in (26):

$$K = \left[\xi^{-1}\mu_1 b_3 b_2^{-2}\right]^{\frac{1}{2}} . \tag{26b}$$

Our next task is to determine the transfer function ϕ. Let the autocovariance generating function $g_{\varepsilon\varepsilon}(z)$ of errors be canonically decomposed as follows

$$g_{\varepsilon\varepsilon}(z) = \psi_\varepsilon(z)\ \psi_\varepsilon(z^{-1}). \tag{27}$$

Assuming $b_2 \neq 0$ Wiener-Hopf technique yields the following solution, Whittle (1963, p. 121 eq. 27). Let superscript 0(*) denote the first term of a Taylor expansion obtained by setting $z = 0$.

$$\phi = \frac{1}{P\psi_\varepsilon}\left[\frac{P\psi_\varepsilon}{\alpha}\right]^{0(*)} + \frac{\mu_1}{P(z)\psi_\varepsilon}\left[\frac{\alpha(z^{-1})\psi_\varepsilon}{P(z^{-1})}\right]_1^{\infty} . \tag{28}$$

If we assume that ε_t and u_t are white noise processes with $\psi_\varepsilon = \sigma_\varepsilon$ and $\psi_u = \sigma_u$ (where σ_ε and σ_u are constants) we have simplification. The first term of (28) becomes

$$K^{-1}(1-\xi z)^{-1}[K\ b_2\ (1-\xi z)\quad (1+b_3 z + b_3^2\ z^2 + \ldots)]^{(0)*} \tag{29}$$

The second term vanishes because terms z^j for $j=1,\ldots\infty$ alone are retained. Hence we have, similar to Whittle's Eq. (10.7.8)

$$\phi = b_2/(1-\xi z). \tag{30}$$

and from (24)

$$\theta = \frac{1}{K(1-\xi z)\sigma_u}\left[\frac{\sigma_u}{K(1-\xi z^{-1})}\right]_0^{\infty} = \frac{1}{K^2(1-\xi z)}. \tag{31}$$

It should be noted from (26 a) and (26 b) that the root ξ and the constant K depend on b_2, b_3 and μ_1.

Thus we have determined the transfer functions ϕ and θ which are involved in the stationary problem. The non-stationary problem is considered in the following subsection.

A-2. Final Solution

In this section we derive an explicit formula for p_t defined in terms of the optimal pricing rule (10) to be chosen by the regulator. Thus we need to determine β^0, $\beta^{(1)}$, $\beta^{(2)}$ and $\beta^{(3)}$. We will first note that the solution (30) and (31) to the stationary problem has indirectly given us $\beta^{(1)}$ and $\beta^{(2)}$. We use (20) and (30) to write

$$\alpha - \beta^{(1)} = \phi^{-1} = (1-\xi z)\, b_2^{-1}$$

Substituting for α we have

$$\beta^{(1)} = (\xi - b_3) b_2^{-1} z \tag{32}$$

Now use (19) and (31) to get

$$\beta^{(2)} = 1/K^2 b_2 \tag{33}$$

Substituting (32) and (33) in (10) we have

$$p_t = \beta^0 + (\xi - b_3)\, b_2^{-1}\, \pi_{t-1} + K^{-2} b_2^{-1}\, \pi_t^* + \beta^{(3)}\, \bar{\pi}^* \tag{34}$$

where β^0 and $\beta^{(3)}$ remain unknown. These have to be determined so as to minimize the remaining terms from (9).

$$V^* = (\bar{\pi}^* - \bar{\pi})^2 + 2\mu_2 \, \bar{p} \, . \tag{35}$$

where $V^* = L - V$, where V is from (15).

We may replace $\bar{p}$ by the right hand side of (12) and write (35) as

$$V^* = (\bar{\pi}^* - \bar{\pi})^2 + 2\mu_2 \left[\beta^0 + \beta^{(1)}\bar{\pi} + (\beta^{(2)} + \beta^{(3)})\bar{\pi}^* \right]. \tag{36}$$

Now we minimize V^* with respect to $\bar{\pi}$

$$\frac{\partial V^*}{\partial \bar{\pi}} = 0 = -2(\bar{\pi}^* - \bar{\pi}) + 2\mu_2 \, \beta^{(1)} \, .$$

Hence using (32) we have

$$\bar{\pi} = \bar{\pi}^* - \mu_2(\xi - b_3)b_2^{-1}z \tag{37}$$

where $\bar{\pi}^*$ may be assumed to be a known number representing the officially announced average "fair rate of return" level permitted by the regulator. From (37) sufficient conditions for "above normal" average rates of return: $\bar{\pi} > \bar{\pi}^*$ are $b_2 > 0$, $\mu_2 > 0$, $\xi < b_3$. In practice, when the regulation is politically sensitive, the average returns satisfy $\bar{\pi}^* > \bar{\pi}$, which holds true when $\mu_2 > 0$ and $\beta^{(1)} > 0$.

Now we determine the average price $\bar{p}$ by using (8)

$$\bar{p} = -(b_1/b_2) + (\bar{\pi}/b_2)(1-b_3)\, . \tag{38}$$

The remaining unknowns, β^0 and $\beta^{(3)}$, can be obtained by using (38) and (12). This gives

$$\beta^0 = -(b_1/b_2)\, . \tag{39}$$

$$\beta^{(3)} = \left[\frac{1}{b_2} - \frac{\xi}{b_2}\right] \frac{\bar{\pi}}{\bar{\pi}^*} - \frac{1}{K^2 b_2}\, . \tag{40}$$

Next, our normative regulatory rule will be obtained by substituting (39) and (40) in (34) as follows:

$$p_t = \frac{-b_1}{b_2} + \frac{\xi - b_3}{b_2} (\pi_{t-1}) + \frac{1}{K^2 b_2} (\pi_t^* - \overline{\pi}^*) + \frac{\overline{\pi}}{b_2} (1-\xi) \tag{41}$$

which is (3.4) in the text after the following manipulations.

Using (38) we can write (41) as

$$(p_t - \overline{p}) = C_1 (\pi_{t-1} - \overline{\pi}) + C_2 (\pi_t^* - \overline{\pi}^*) \tag{42}$$

where

$$C_1 = (\xi - b_3)/b_2 \text{ and } C_2 = 1/ (K^2 b_2) \tag{43}$$

Equation (4.2) of the text uses (42) after adding an error term.