Journal of Applied Economics, Vol. IV, No. 1 (May 2001), 163-186

TECHNICAL EFFICIENCY, ALLOCATIVE EFFICIENCY, AND THE IMPLEMENTATION OF A PRICE CAP PLAN IN TELECOMMUNICATIONS IN THE UNITED STATES

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Incentive regulation is designed to improve productive efficiency, enhance service quality and consumer welfare, and reduce the costs of regulation. The issue that is considered here is whether incentive regulation in the form of a price cap applicable to interstate access service to local loops in the telecommunications industry in the United States has resulted in an increase in the technical efficiency and allocative efficiency of local exchange carriers. The results suggest that for changes in technical efficiency, there is a definite randomness between 1985 and 1993 with technical efficiency increasing in some years and decreasing in others. Subsequent to 1993, however, there is a consistent improvement in technical efficiency. Given that incentive regulation in the form of price caps was implemented in 1991, it is likely that some portion of the improvement in technical efficiency subsequent to 1993 is attributable to incentive regulation.

JEL classification codes: L1

Key words: allocative efficiency, incentive regulation, price caps, technical efficiency, telecommunications

I. Introduction

An important regulatory tool in the telecommunications industry in the

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* The views expressed are those of the author and do not necessarily represent the policies of the Federal Communications Commission or the views of other Federal Communications staff members.

United States is incentive regulation. A number of factors led away from rate-of-return (cost-based) regulation and toward a regulatory approach that ostensibly provides incentives for increasing productive efficiency thereby allowing firms to share in the social gains from efficiency with increased profits.

The basic structure of incentive regulation as it has most commonly been adopted in the telecommunications industry in the United States is in the form of price caps. The issue that will be explored below is whether, de facto, price caps have resulted in an increase in productive efficiency. Before exploring this issue, however, some background is needed.

II. Background

For several decades, there has been substantial criticism of rate-of-return regulation. From the initial formal analysis by Averch and Johnson (1962), concerns have centered around the potential for inefficiencies. It was suggested that a profit-maximizing firm under rate-of-return regulation fails to minimize the cost of producing any observed level of output, that these productive inefficiencies might be large, and that the firm might even build up its rate base by selling competitive outputs at a price below marginal cost. Although a number of questions have been raised over the years about the original analysis, many of the basic concerns about rate-of-return regulation persist (Kahn, 1970, and Sherman, 1985, 1992).

Despite the concern with the presence of inefficiencies under rate-of-return regulation, it was not abandoned in the telecommunications industry until the decade of the 1980s. The developments crucial to ushering in the era of incentive regulation in telecommunications are discussed in the *Notice of Inquiry in the Matter of Price Cap Performance Review for AT&T* (7 FCC Rcd No. 17). In this Notice of Inquiry (NOI), two factors are identified including the increasing degree of competition and rapid changes in technology in telecommunications markets as the rationale for adopting incentive regulation:

> “The Commission began development of the AT&T Price Cap Plan in 1987, as part of a fundamental reappraisal of the rate regulation it applies to telecommunications common carriers. The reappraisal was precipitated by the changes that have swept the telecommunications industry in the last few decades. ... Traditional "cost-plus" rate of return regulation focuses on establishing a reasonable limit on the carrier's profits. ... The limitations and drawbacks of such "cost-plus" regulation include distorted incentives in capital investment, encouragement of cost shifting when the carrier also participates in more competitive markets, and little incentive to introduce new and innovative services. The Federal Communications Commission has concluded in the past that rate of return regulation does not encourage optimal efficiency. Under traditional rate of return regulation, the carrier’s allowed profits are computed from its total invested capital, whether or not the carrier is using capital, labor, operational methods, and pricing in the most efficient manner. To maximize profits, the company has an incentive to manipulate its inputs of labor and capital, without regard to efficiency, and to adopt strategies and pricing based on what it expects the regulatory agency might wish, not necessarily what best serves its customers and society” (7 FCC Rcd No. 17, p. 5322).

Rate-of-return regulation, as noted previously, has been replaced by incentive regulation in the telecommunications industry in the United States. Incentive regulation has a number of desirable properties. These include technical efficiency (i.e., short-run cost minimization), dynamic efficiency (i.e., long-run cost minimization), enhanced service quality and consumer welfare, and reduced costs of regulation. Incentive regulation plans also often have socially beneficial equity and redistributional properties. Thus, preserving low basic local service rates is a common property of incentive plans. In some situations, a precondition for earnings sharing or other departures from strict rate-of-return regulation is a freeze on basic local service rates for the duration of the incentive plan. Rate stability is a broader, but related, objective of incentive regulation (Kridel et al., 1996). Additional desirable properties suggested by Littlechild (1983), one of the earliest proponents of incentive regulation, include the protection of consumers against monopoly, promotion of competition, enhancement of innovation, and improvement of the profitability of the regulated firm.

There has been considerable discussion of the extent to which these beneficial objectives can be realized. Some of this discussion has been at the theoretical level. For example, a comparison between innovation under rate-of-return regulation and under incentive regulation is provided by Cabral and Riodan (1989). Their results generally support the identifiable beneficial properties of incentive regulation. With incentive regulation, Vogelsang (1988, 1991) demonstrates convergence to efficient prices (both access and usage) under stationary cost and demand conditions while Brennan (1989) finds that cost and demand change when this convergence does not occur.

With regard to the implementation of incentive regulation, a number of practical concerns have been raised. For example, Sappington (1980) argues that incentive regulation introduces the potential for pure waste and involves the purchase of inputs which have no productive value. Kridel, Sappington, and Weismen (1996), on the other hand, survey a number of empirical studies that ostensibly provide evidence that productivity, infrastructure investment, profit levels, and new service offerings have increased under incentive regulation. It appears, therefore, that the attainability of many of the desirable properties of incentive regulation is an empirical issue.

III. Incentive Regulation and Price Caps

Incentive regulation is typically defined as the implementation of rules that encourage a regulated firm to achieve desired goals by granting some, but not complete, discretion to the firm. Three aspects of this definition of incentive regulation are important. First, regulatory goals must be clearly specified before incentive regulation is designed. The properties of the best incentive regulation plan will vary according to the goals the plan is designed to achieve. Second, the regulated firm is granted some discretion under incentive regulation. For example, while the firm may be rewarded for reducing its operating costs, it is not told precisely how to reduce these costs. Third, the regulator imposes some restrictions on relevant activities or outcomes under incentive regulation (Baron, 1991, and Bernstein and Sappington, 1999).

One popular incentive regulation plan is the price cap plan. The central idea behind price cap regulation is to control the prices charged by the regulated firm, rather than its earnings. Essentially, price cap regulation plans require the regulated firm's average real prices to fall annually by a specified percentage (Mitchell and Vogelsang, 1991). This percentage is nominally referred to as the "X-factor" or the productivity offset.

In the case of incumbent local exchange carriers (LECs) regulated by the Federal Communications Commission, a price cap index (PCI) for common line interstate access and for traffic sensitive switched interstate access is adjusted annually pursuant to the PCI relationship defined in the *Code of Federal Regulations*.[1] The PCI relationship consists of a measure of inflation, in this case the Gross Domestic Product Price Index (GDP-PI), minus the X-factor, plus or minus any permitted exogenous cost changes.

For LEC interstate access service, it has been argued in the *Price Cap Performance Review for Local Exchange Carriers* in 1995 (10 FCC Rcd at 9002) that applying price cap regulation allows the Federal Communications Commission, as closely as possible, to replicate the effects of a competitive market.[2] That is, competition should be the model for setting just and reasonable LEC rates based on a PCI because "Effective competition encourages firms to improve their productivity and introduce improved

[1] Section 61.45 (b) of the Commission's rules.

[2] Note that all Federal Communications Commissions documents referred to are accessible via the Federal Communications Commission's web site http://www.fcc.gov.

products and services, in order to increase their profits. With prices set by marketplace forces, the most efficient firms will earn above-average profits, while less efficient firms will earn lower profits, or cease operating. Over time, the benefits of competition flow to customers and to society, in the form of prices that reflect costs, maximize social welfare, and efficiently allocate resources (p. 9002)."

IV. Measuring the Change in Productive Efficiency

Whether the desirable properties of incentive regulation are realized is an empirical issue. What will be examined is whether incentive regulation in the form of price caps has resulted in an improvement in productive efficiency. The focus will be incumbent local exchange carriers. It is not a straightforward exercise, however, to measure the change in productive efficiency. First, LECs are involved in three different markets where they produce identifiable outputs including local service, intrastate toll/access service, and interstate access to local loops. Incentive regulation, however, is applicable only to interstate access (both common line and traffic sensitive switched access).[3] The measurement problem arises because it is not possible to apportion accurately inputs among the three separate services produced. Hence, using LEC data and if incentive regulation has changed productive efficiency, it will be possible to evaluate the relative change but it is not possible to indicate the absolute

[3] Interstate access service has grown much more rapidly on average than demand for local service and intrastate toll/access service. The data on this are clear. Thus, in the presence of economies of density, there is every reason to expect that productivity enhancements experienced historically in the interstate access market would be substantially greater than the overall rate of productivity growth experienced by LECs in supplying all services (Shin and Ying (1993)). Most of the productivity growth experienced in the telecommunications industry is related to reductions in switching costs and to savings in transmissions costs which occur as a result of using electronics to expand the carrying capacity of transmissions facilities. In contrast productivity growth in supplying loop services has been relatively lower.

magnitude of that change as applicable to interstate access service to local loops.

Productivity is just the ratio of output to input. Productivity changes due to differences in production technology, differences in the efficiency of the production process, and differences in the environment in which production takes place. The problem is to attribute productivity variation to these sources and an unattributed residual -Abramovitz's (1956) famous “measure of our ignorance.” Solow (1957) sought to attribute output growth to input growth and technical change by distinguishing movements along a production frontier from shifts in the frontier. Economies of scale were added to the explanation by Brown and Popkin (1962). David and van de Klundert (1965) allowed technical change to be biased. The effects of scale economies and technical change on productivity growth were translated into their effects on productions costs by Ohta (1974) and Binswanger (1974). Only Nishimizu and Page (1982), who decomposed productivity into shifts in the production frontier and movements toward or away from it, attempted to incorporate efficiency change into a model of productivity change.

In the analysis designed to measure productive efficiency, there are two commonly used approaches -the econometric approach and the data envelopment analysis approach.[4] The econometric approach to incorporating efficiency change into a model of productivity growth began with the stochastic frontier production function, proposed independently by Aigner et al. (1977) and Meeusen and van den Broeck (1977). In a deterministic frontier production function setting, deviations from the production frontier might not be entirely under the control of the firm being studied. Random equipment failures, for example, might appear as inefficiency. Additionally, any error or imperfection in the specification of the model could translate into an increase in the measure of inefficiency. The stochastic frontier production function postulates the

[4] These two approaches are sometimes referred to as the parametric and the nonparametric approaches.

existence of technical inefficiencies of production of firms involved in producing a particular good or service. The amount by which a firm lies below its production frontier is regarded as a measure of inefficiency. The approach begins with a cross-sectional translog cost function and a system of input share equations with technical and allocative inefficiency allowed. Technical change is incorporated into the specification by adding time as an argument in the cost function and the share equations. The computational burden, however, is great. In theory, however, the specification does allow productivity change as reflected by a change in the cost function to occur as a result of scale economies, technical change, and changes in technical and allocative efficiency. Additionally, while the parametric approach can deal with multiple inputs, it does not allow for multiple outputs (Greene (1993)). The approach does allow, however, for the determination of the impact of specific factors (e.g., research and development expenditures) on productive efficiency. This is not the case with the data envelopment analysis approach. Shin and Ying (1993), among others, illustrate the use of this econometric approach in an application to the telecommunications industry.

An alternative approach to measuring productive efficiency is the mathematical programming approach known as data envelopment analysis (DEA). Drawing on the work of Debreu (1951) and Koopmans (1951), Farrell (1957) argued that it is practical to measure productive efficiency based on a production possibility set consisting of the conical hull of input-output vectors. This framework was generalized to multiple outputs and reformulated as a mathematical programming problem by Charnes, Cooper, and Rhodes (1978). The DEA approach does not require any assumptions about the functional form, in contrast to the econometric approach. DEA, however, is non-stochastic which suggests that random variation in the data can potentially impact the efficiency measure. Efficiency in a given time period is measured relative to all other time periods with the simple restriction that production of each output in each time period lie on or below the efficient frontier. It is the approach that will be used here.

In the programming method, DEA "floats a piecewise linear surface to rest on the top of the observations (Seiford and Thrall, 1990, p.8)." The facets of the hyperplane define the efficiency frontier, and the degree of inefficiency is quantified and partitioned by a series of metrics that measure various distances from the hyperplane and its facets (Leibenstein and Maital, 1992).

V. A Brief Description of DEA

The objective is to determine the relative efficiency for each year. Efficiency is measured by the ratio of inputs to outputs. For multiple outputs and inputs, the appropriate efficiency index is that of summed weighted outputs, divided by summed weighted inputs (Fare et al. (1994)).

Assume that there are K inputs and M outputs for each of N time periods. For time period i, these are represented by vectors x_i and y_i, respectively. The K X N input matrix, X, and the M X N output matrix, Y, represent data for all N time periods.

The mathematical programming formulation of the efficiency problem asks what output and input weights would optimize efficiency. That is, the problem is given as

$$\text{minimize}_{\theta,\, \lambda}\ \theta \tag{1}$$

subject to

$$-y_i + Y\lambda \geq 0,$$

$$\theta x_i - X\lambda \geq 0,$$

$$N1'\lambda = 1, \text{ and}$$

$$\lambda \geq 0$$

where N1 is an N X 1 vector of ones, θ is a scalar, and l is an N X 1 vector of weights or scale variables.[5] The value of θ is the efficiency score for time period i. It will satisfy $\theta \leq 1$, with a value of 1 indicating a point on the frontier and hence technical efficiency. Note that the linear programming problem must be solved N times, once for each time period in the sample. A value of θ is obtained for each time period.

DEA can be specified as either an output-maximizing problem or an input-minimizing problem. Moreover, each DEA specification has a dual. DEA provides a set of scalar measures of efficiency. These measures come in pairs, one set for the input-oriented problem and one set for the output-oriented problem.

As proposed by Farrell,[6] the two primary scalar measures of efficiency for the input-oriented problem are

(1) Technical efficiency (TE) which is just the proportional reduction in inputs possible for a given level of output in order to obtain the efficient input use,[7] and

(2) Allocative efficiency (AE) which reflects the ability of the firm to use the inputs in optimal proportions, given their respective prices.

The two measures can be combined to give a measure of total economic efficiency. It is the product of the two efficiency measures.

DEA makes no *a priori* distinction between the relative importance of any combination of outputs or inputs. While DEA is nonparametric, this does

[5] The fact that the weights sum to 1 indicates that a piecewise linear production surface can exhibit increasing, constant, or decreasing returns-to-scale.

[6] Some of Farrell's terminology differs from that used here. He used the term price efficiency instead of allocative efficiency and the term overall efficiency instead of economic efficiency. The terminology used here conforms to that customarily found in the literature on DEA.

[7] TE measures only that portion of inefficiency that could be eliminated by proportional reduction of inputs. It is the proximity of the data point (y_i, x_i) to the facet of the piecewise linear envelopment surface. Even after reducing input use by (1 - TE), however, some inputs may still exhibit slack (i.e., be used inefficiently).

not imply that it is not based on underlying economic theory. Thus, for example, assumptions about the underlying technology will determine whether the efficient frontier is forced through the origin (implying constant returns to scale (CRS))[8] or allowed not to pass through the origin (implying variable returns to scale (VRS)). The CRS assumption is appropriate only when production is optimal (i.e., corresponding to the flat portion of the long run average cost curve). A number of factors including, for example, imperfect competition or regulation may cause suboptimal production. The use of the CRS specification when production is not at the optimal level will result in measures of technical efficiency which are confounded by scale efficiencies (Ali and Seiford, 1993). The use of the VRS specification, as is done here, permits the calculation of technical efficiencies devoid of these scale efficiency effects.[9]

To measure both technical and allocative efficiency, it is necessary to have price information on the inputs and be willing to assume that cost minimization is the objective.[10]

Assuming variable returns to scale and cost minimization, technical efficiencies would first be obtained by solving the problem given in (1). Next, the following cost minimization problem is solved:

$$\text{minimize}_{\lambda,\, x_i}\; w_i x_i^* \qquad (2)$$

subject to

$$-y_i + Y\lambda \geq 0,$$

[8] The original formulation in Charnes et al. (1978) assumed constant returns to scale (CRS). Subsequent formulations, e.g., Banker et al. (1984), permit variable returns to scale.

[9] The variable returns to scale formulation of the problem can be converted to a constant returns to scale problem by deleting the convexity constraint, $N1'\lambda = 1$.

[10] Note that is also possible to assume revenue maximization as the objective. See, e.g., Lovell (1993).

$\theta x_i - X\lambda \geq 0,$

$N1'\lambda = 1$, and

$\lambda \geq 0$

where w_i is a vector of input prices for time period i and x_i^* (which is calculated by the linear program) is the cost-minimizing vector of input quantities for time period i, given the prices, w_i and the output levels, y_i.

Total economic efficiency for time period i is calculated as $EE = w_i x_i^* / w_i x_i$. This is just the ratio of minimum cost to observed cost.

This is the methodology that will be used in assessing whether incentive regulation in the form of price caps has had any demonstrable impact on the technical efficiency and the allocative efficiency of LECs. Before implementing the approach, a discussion of the data is in order.

VI. Data Issues

Measurement of technical efficiency and allocative efficiency of LECs is based on the LECs regulated books of account excluding miscellaneous services. Thus, the measurement is based on the productivity of all LEC activities including local service, intrastate toll/access service, and interstate access to local loops. The measurement is for the period 1985 through 1998. Just the Regional Bell Operating Companies are considered.[11] In 1998 the

[11] The Regional Bell Operating Companies are holding companies. Each Regional Bell Operating Company owns two or more Bell Operating Companies. Currently, the four Bell Operating Companies consist of the following LECs: Illinois Bell Telephone Company, Indiana Bell Telephone Company, Michigan Bell Telephone Company, The Ohio Bell Telephone Company, Wisconsin Bell, Inc., Bell Atlantic - Delaware, Inc., Bell Atlantic - Maryland, Bell Atlantic - New England Telephone and Telegraph Company, Bell Atlantic - New Jersey, Inc., Bell Atlantic - New York Telephone Company, Bell Atlantic - Pennsylvania, Inc., Bell Atlantic - Virginia, Inc., Bell Atlantic - Washington, DC, Inc.,

Regional Bell Operating Companies accounted for 79.4 percent of total common carrier revenue and 82.9 percent of local network revenue (Federal Communications Commission, 1998). All of the LECs included in the analysis are subject to price caps previously discussed.[12]

A. Output Measures

Three separate measures of output are used in the analysis - local service, intrastate toll/access service, and interstate service. Local service volume is measured by the number of local dial equipment minutes. State toll and intrastate service volume is measured by dial equipment minutes as well. These data are taken from the Federal Communications Commission's Monitoring Reports. An interstate quantity index to measure interstate service is constructed using the physical measures of three services including the number of access lines, the number of interstate switched access minutes, and the number of interstate special access lines. The number of access lines is measured by the sum of the number of business, public, and residential access lines. The data on the number of special access lines, the number of business access lines, residential access lines, and public access lines are taken from the Federal Communications Commission's *Statistics of Communications Common Carriers* for 1985 through 1998. Interstate switched access minutes are from the Federal Communication Commission's Monitoring Reports.

Bell Atlantic - West Virginia, Inc., BellSouth Telecommunications, Inc., Nevada Bell, Pacific Bell, Southwestern Bell Telephone Company, and U.S. West Communications, Inc. These LECs correspond closely to the original local phone companies that the Justice Department divested from AT&T in 1984.

[12] Other price cap LECs include Aliant (AllTel) Communications Company, Cincinnati Bell Telephone Company, Citizens Telecommunications Company, Frontier Telephone of Rochester, GTE, and Sprint Local. These LECs are excluded from the analysis because the requisite data are not available for the entire historical period 1985-1998.

A service's share of total interstate revenue is used to weigh each service in the construction of the measure of interstate output. That is, the number of access lines is weighted by the End User Common Line revenue share of total interstate revenues. The number of switched access minutes is weighted by the switched access revenue share, and the number of special access lines is weighted by the special access revenue share. A Fisher Ideal Quantity Index is then constructed (Fisher, 1922).[13] The composite Fisher Ideal Interstate Quantity (Output) Index is derived by chaining the Fisher Interstate Ideal Output Index.

B. Input Quantity Measures

Three separate inputs are considered -labor, capital, and materials. The measure of the quantity labor is based on annual accounting data for the number of employees from the Federal Communications Commission's *Statistics of Communications Common Carriers.* Since there is no objective way to account for the contribution of part-time versus full-time employees, just the total

[13] The Fisher Ideal Index is the geometric average of the Laspeyres Index and the Paasche Index. This index is desirable because it is calculated using the weights of adjacent years. During periods of relatively substantial and significant changes in prices, a significant bias can appear in fixed weight measures, even during periods close to the base period. Expanding beyond just two periods, a chained Fisher Ideal Quantity Index can be constructed between periods 0 and t. It is the product of each of the Fisher Ideal Quantity Indexes between periods 0 and t. All input and output quantity indexes are chained Fisher Ideal Quantity Indexes. The chained Fisher Ideal Quantity Index addresses one of the most fundamental problems in measuring output -the choice of the base period with which all other periods are compared. Since changes in the Fisher Ideal Quantity Index are calculated using weights of adjacent years, the chaining of the annual changes allows for the effect of changes in relative prices. Thus, the Fisher Ideal Chained Quantity Index calculates an index that is appropriate for each period and avoids having to update a fixed-weight index. It also negates the substitution bias that is inherent in a fixed-weight index. Finally, the chain-type index provides a more accurate measure of current period output during periods of significant price changes.

number of employees is used as the labor input measure. This, however, does not introduce a substantial bias in the labor quantity measure since part-time employees accounted for less that 0.7 percent of the workforce in 1998.

The capital input quantity index series is computed by dividing current period capital stock by the base period capital stock. The capital stock is computed based on the perpetual inventory method (Goldsmith, 1951).[14]

The materials quantity is computed as materials expense divided by a materials price index. Materials expense is a residual. It is the difference between total operating expense and the sum of labor compensation and depreciation and amortization expense. The materials price index comes from the Input/Output Tables compiled by the Bureau of Economic Analysis of the U.S. Department of Commerce.

C. Price Indexes

In order to correct the miscalculation common in productivity studies intended to be used in a regulatory setting, it is necessary to replace the productivity study's imputed cost of capital with a competitive cost for the inputs during the historical years. To do so requires the adoption of a surrogate to emulate a competitive cost of capital for LECs because LECs have never operated in a competitive market. An independent price series is employed to compute the annual change in the cost of capital for a competitive market. Specifically, Moody's Baa corporate bond rate reported in the *1999 Economic Report of the President* (Table B-73) is used to calculate the adjustment (Council of Economic Advisors (1999)).[15] Combining the base year imputed

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[14] Just a single capital measure is considered. This is based primarily on the nature of the capital data that are available and its level of disaggregation. The interested reader is referred to the deliberations in CC Docket No. 94-1 accessible via the Federal Communications Commission web site.

[15] Any index for a competitively determined cost of capital should be acceptable because changes in the cost of capital in competitive markets are similar across markets. The use of a

cost of capital with the change in the competitive cost of capital gives an independent competitive cost of capital for LECs in each year of the historical period.[16]

The materials price index is based on those categories of expenditures from the National Input-Output Tables compiled by the Bureau of Economic Analysis of the U.S. Department of Commerce that focus on materials purchases by communications industries. The materials price index is a Tornqvist index. Total labor compensation divided by the number of employees gives a simple way of computing the average annual price of labor.

Finally, all prices are in real terms. They are deflated by the gross domestic product price index (GDP-PI).

A cursory examination of the data reveal some interesting trends. Local service output shows a much more rapid increase beginning in 1994 than it had previously. Between 1985 and 1994, local service output grew at an annual average rate of 2.2 percent. Subsequently, it has grown at a 6.4 annual percentage rate. This is attributed to an increase in Internet traffic. Interstate service output is the most rapidly growing component of LECs' activities, averaging 6.1 percent per year.

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different series would yield comparable results given the competitive nature of financial markets. For example, the correlation over the period 1985-1998 between Moody's Aaa corporate bond rate and the Baa rate used is 0.99. Analogously, the correlation between the 10-year U.S. Treasury securities rate and the 30-year U.S. Treasury securities rate and Moody's Baa rate over the same period is 0.99 and 0.98, respectively. In terms of changes in the absolute level of the series, the correlation between Moody's Baa corporate bond rate and Moody's Aaa corporate bond rate, the 10-year U.S. Treasury securities rate, and the 30-year U.S. Treasury securities rate over the period 1985-1998 is 0.99, 0.98, and 0.97, respectively.

[16] The base year is 1991. This is the first full year of LEC price caps. The implicit assumption is that the cost of capital for this year was at the competitive level. That is, it is assumed that LECs earned a normal return in that year. In fact immediately prior to the implementation of price caps in 1991, the Federal Communications Commissions computed a competitive rate of return of 11.25 percent (Matter of Represcribing the Authorized Rate of Return for Interstate Service for Local Exchange Carriers, Order, CC Docket Number 89-624, 5 FCC Rcd 7507, 7532.) In 1991, LECs on average earned an 11.25 percent rate of return (ARMIS Report 43-02 for 1991).

On the input side, labor input fell by 3.6 percent per year. Between 1985 and 1998, the price of labor increased in real terms at a 3.6 percent annual rate. In terms of total compensation, the amount paid for labor was approximately the same in 1985 as it was in 1998 even though the number of workers in the aggregate had been reduced. The reason for this, at least in part, is that, coincident with the adoption of price cap plans, labor force reductions were accomplished by offering employees monetary incentives to leave the company (i.e., buyouts). There is some variability in the applicable accounting rules,[17] but these payments were generally accrued as one-time charges against current earnings (Kridel et al., 1996).

There is an identifiable increase in the capital input quantity beginning in 1996. This is due primarily to relatively large increases in investment in both central office switching equipment and cable and wire facilities. Finally, reflecting financial market conditions, the cost of capital exhibits a decline over the historical period.

VII. Measuring Technical Efficiency and Allocative Efficiency of LECs

Data envelopment analysis with a cost minimizing objective and assuming variable returns to scale is used to compute the technical efficiency and allocative efficiency of LECs over the 1985 to 1998 period.[18] The results are presented in Table 1.

The results are fairly revealing with regard to both technical efficiency and allocative efficiency. For technical efficiency there is a definite randomness between 1985 and 1993 with technical efficiency increasing in some years and decreasing in other years. (Recall that the performance for any given year is relative to the best observed practice which occurs in 1998.) Subsequent

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[17] See, e.g., Financial Accounting Standards Board Rule (FASB) Number 106.

[18] The problem is solved using the Data Envelopment Analysis Program (Coelli, 1996).

Table 1. Technical Efficiency and Allocative Summary for LECs

Year	Technical Efficiency	Allocative Efficiency	Total Economic Efficiency[1]
1985	0.902	0.557	0.502
1986	0.872	0.588	0.513
1987	0.904	0.594	0.537
1988	0.884	0.641	0.567
1989	0.930	0.660	0.613
1990	0.948	0.695	0.658
1991	0.930	0.748	0.696
1992	0.926	0.767	0.710
1993	0.918	0.802	0.736
1994	0.931	0.867	0.807
1995	0.955	0.921	0.880
1996	0.984	0.965	0.950
1997	0.988	0.991	0.980
1998	1.000	1.000	1.000

[1] Total economic efficiency equals technical efficiency times allocative efficiency.

to 1993, however, there is a consistent improvement in technical efficiency. This is due primarily to relatively large increases in investment in both central office switching equipment and cable and wire facilities. In the case of switching equipment, major investments were made, for example, in frame relays[19] and ATM.[20] For cable and wire facilities, substantial investments were

[19] Frame relay services employ a form of packet switching. The packets are in the form of frames which are variable in length.

[20] Asynchronous transfer mode (ATM) is a high bandwidth, low-delay, connection- oriented, packet-like switching and multiplexing technique.

made in optical fiber.[21] The increase in the demand for access to the Internet as well as the need by businesses to transfer large amounts of data have driven the growth in investment designed to transfer higher levels of bandwidth at faster rates (Telecommunications Industry Association, 2000). Additionally, given that incentive regulation in the form of price caps was implemented for LECs in 1991, it is likely that some portion of this consistent improvement in technical efficiency subsequent to 1993 is attributable to incentive regulation.

A pronounced upward trend in allocative efficiency is observed beginning in 1985, the beginning of the sample period. Hence, it is more problematic than it is for technical efficiency to attribute the improvement in allocative efficiency to the adoption of incentive regulation in the form of price caps. It is more likely an artifact of the divestiture of AT&T although some indeterminant portion is probably associated with the implementation of price caps.

VIII. Comparison

How do the results obtained here compare with similar studies of industries subject to incentive regulation? Unfortunately, there is a dearth of studies that specifically look at the productivity impact of incentive regulation in the telecommunications industry.[22] There are just a few such studies. Tardiff and Taylor (1993) test whether incentive regulation affects the rate of total factor productivity growth over time. Measuring total factor productivity using the conventional growth accounting approach,[23] they pool cross-section and time series data over the period 1984 to 1990 for large LECs in the United States.

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[21] Fiber optics is a technology whereby electrical signals are converted into optical signals that are transported through glass fiber and then reconverted by receivers at the other end into electrical signals.

[22] A generic review of studies on the effects of incentive regulation is provided by Kridel et al. (1996).

[23] Uri (2000) examines the shortcomings associated with using the conventional growth accounting approach for total factor productivity in the telecommunications industry.

They conclude that incentive regulation increases annual productivity growth by about 2.8 percent. This increase in productivity is driven equally by higher output and lower input growth. Tardiff and Taylor also find that LECs that operate under incentive regulation are able to produce the same output with about 6 percent less labor than LECs that do not operate under incentive regulation.

The other study that explicitly looks at the effect of incentive regulation on LEC productivity is that by Majumdar (1997).[24] Using data envelopment analysis based on three outputs and three inputs for the period 1988 to 1993,[25] Majumdar finds that price caps plans as a replacement for rate of return regulation has a marginally statistically significant positive, but lagged, effect on the technical efficiency of local exchange carriers. It is claimed that the impact of price caps on scale efficiency are positive, although the reported results are only marginally statistically significant. For neither technical efficiency nor scale efficiency are the effects of price caps on productivity quantified.

IX. Conclusion

Incentive regulation in the form of price caps is now an important regulatory tool in the telecommunications industry in the United States. The objective of incentive regulation is to improve productive efficiency, enhance service

[24] This study is an update of Majumdar (1995).

[25] The outputs consist of the number of local calls, the number of intrastate toll calls, and the number of interstate calls. There are significant limitations associated with these output measures and discussed in Appendix B (The 1999 Staff TFP Study by Noel D. Uri) in *Further Notice of Proposed Rulemaking,* CC Docket No. 94-1, Released November 15, 1999. The major problem is that they do not accurately portray the growth in LEC output. Inputs consist of switches, number of lines, and number of employees. These measures of inputs also suffer limitations because they do not account for all LEC inputs. A extended discussion of the appropriate output and input measures to use in measuring LEC productivity can be found in Comments and Reply Comments to CC Docket No. 94-1 filed in January 2000. These, as noted previously, can be accessed via the Federal Communications Commission web site.

quality and consumer welfare, and reduce the costs of regulation. The issue that has been explored here is whether incentive regulation in the form of a price cap applicable to interstate access service to local loops has resulted in an increase in the technical efficiency and allocative efficiency of local exchange carriers.

After discussing the reasons for adopting incentive regulation, the nature of price caps is explored followed by an overview of the methodology for measuring the effects of incentive regulation on productive efficiency. This methodology is data envelopment analysis and allows for the measurement of both technical efficiency and allocative efficiency. A discussion of the data on the three output measures and three input measures for the period 1985-1998 is subsequently provided.

The results indicate that for technical efficiency, there is a definite randomness between 1985 and 1993 with technical efficiency increasing in some years and decreasing in other years. Subsequent to 1993, however, there is a consistent improvement in technical efficiency. Given that incentive regulation in the form of price caps was implemented for LECs in 1991, it is likely that some portion of the improvement in technical efficiency subsequent to 1993 is attributable to incentive regulation.

A pronounced upward trend in allocative efficiency is observed beginning in 1985. It is problematic, however, to attribute the improvement in allocative efficiency to the adoption of incentive regulation in the form of price caps. It is more likely an artifact of the divestiture of AT&T although some indeterminant portion is probably associated with the implementation of price caps.

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