

Productivity Growth in Telecommunications: The Case of Tennessee

CHRISTOPHER C. KLEIN*

Middle Tennessee State University, Murfreesboro, TN

Abstract

A Divisia index of total factor productivity (TFP) growth is calculated for each of 16 regulated local telephone companies operating in Tennessee over the years 1989 through 1993. Year over year changes in TFP, in Tornqvist form, yield a growth in total factor productivity estimate for each company. These growth rates, however, contain the effects of both scale and technical change. Using the method suggested by Caves and Christensen, the effects are decomposed indirectly by regressing the annual percentage changes in TFP growth against measures of scale, service density, and network size. The results are consistent with the findings of economies of density and nearly constant returns to scale prevalent in the telecommunications literature.

Key words: total factor productivity, telecommunications, network size

JEL category: L96, L51, O30

*Christopher C. Klein, Associate Professor, Economics and Finance Department, Middle Tennessee State University, Murfreesboro, TN 37132, USA, phone: 615-904-8570, fax: 615-898-5045, e-mail: cklein@mtsu.edu.

Introduction

Productivity growth in telecommunications has become a prominent issue in the United States as the Federal Communications Commission (FCC) imposed price-cap regulation on AT&T and, later, on the interstate services of the Bell Operating Companies (BOCs). Under price caps, service prices are adjusted annually using a formula incorporating the inflation rate, a productivity growth rate, and other factors. Many of the states have adopted similar regulatory schemes for AT&T's intrastate services. As the state and federal governments relax regulation and allow competitive entry in local telecommunications, price caps are suggested as the appropriate regulatory method for the former local monopolies in the face of entry.

An evaluation of any local price capping formula requires estimates of local productivity growth factors. Here, a Divisia index of total factor productivity (TFP) growth is calculated for each of 16 regulated local telephone companies operating in Tennessee over the years 1989 through 1993. These year over year changes in TFP, in Tornqvist form, yield the growth in total factor productivity estimated for each company. The results suggest not only the magnitude and short-term (in)stability of the productivity factor for a local price-cap formula, but also whether the same factor is appropriate for firms of diverse size and operating characteristics.

Previous estimates of productivity growth in the telecommunications industry (Christensen, Schoech, and Meitzen; Crandall; Denny, Fuss and Waverman; Staranczak, Sepulveda, Dilworth and Shaikh) have looked to aggregate national data in calculating TFP indices. This tells us little about the effect of productivity growth on the intrastate, rate-of-return (R-O-R) regulated operations of individual companies within individual states, nor does it indicate the likely price effects of adopting price regulation over R-O-R at the state level. For these reasons, the intrastate jurisdictional costs, revenues, and investment are used for the TFP

calculations for the Tennessee companies, and the results are directly comparable to R-O-R outcomes.

These growth rates, however, contain the effects of both scale and technical change. Direct decomposition of these effects is possible, but requires data intensive estimation of cost function parameters. Caves and Christensen have shown that TFP growth rates can be indirectly decomposed into scale, density, and network effects. Here, the effects are decomposed indirectly by regressing the annual percentage changes in TFP growth against measures of scale, service “density” and network size. The results are consistent with the findings of economies of density and nearly constant returns to scale prevalent in the telecommunications literature (Bellcore; Crandall and Galst; Gasmi, Laffont, and Sharkey; Kwoka; Shin and Ying; Staranczak, et al; Waverman).

To these ends, several tasks are undertaken in the sections that follow. First, the theoretical formulas for TFP calculation are reviewed and the relationship of price caps to R-O-R derived. Next, the data and the calculation of the discrete Tornqvist approximations to the continuous TFP growth rate Divisia indices are discussed. Then, the resulting TFP growth rate indices are compared to national and international telecommunications indices for the post-divestiture years. Finally, regression results seeking to explain the sources of TFP growth are reviewed, followed by a short conclusion.

Total Factor Productivity Growth Under R-O-R Regulation

Following Christensen, et al, (1994) the rate of growth in TFP is defined as the rate of growth of total output less the rate of growth in total input:

$$tfp = \sum_i m_i y_i - \sum_j s_j x_j \quad (1)$$

where tfp is the rate of growth in TFP, m_i is the revenue share of output i and y_i is the rate of change in production of output i , s_j is the cost share of input j and x_j is the rate of change in use of input j . The use of revenue shares for weighting outputs has been criticized for overstating TFP growth rates when relative output prices do not reflect relative marginal costs. Nevertheless, the revenue shares are appropriate for calculating TFP growth rates reflecting productivity effects on rate of return regulation and for comparison with price regulation.

Indeed, the expression in (1) can be related to the rate of growth of revenues and costs, and to rate of return. First, write the rate of growth in revenues as

$$r = \sum_i m_i p_i + \sum_i m_i y_i \quad (2)$$

where p_i is the rate of growth in output price i . Similarly, the rate of growth in total cost is

$$c = \sum_j s_j w_j + \sum_j s_j x_j \quad (3)$$

where w_j is the rate of change in input price j . Combining (2) and (3) leads to

$$\sum_i m_i p_i = \sum_j s_j w_j - \left(\sum_i m_i y_i - \sum_i s_j x_j \right) = \sum_j s_j w_j - tfp . \quad (4)$$

This shows that the rate of change in output prices equals the rate of change in input prices less the rate of change in TFP.

The result in (4) can be related to rate of return by breaking out the capital input and taking capital “cost” as the residual of revenue less variable cost:

$$\sum_i m_i p_i = \sum_{j \neq k} s_j w_j - tfp + s_k w_k \quad (5)$$

Now solve (5) for $s_k w_k$, the cost-share weighted rate of change in capital cost,

$$s_k w_k = \left(\sum_i m_i p_i - \sum_{j \neq k} s_j w_j \right) + tfp . \quad (6)$$

This says that the cost-share-weighted rate of change in rate of return to capital is equal to the rate of change in output prices less the rate of change in variable input prices, plus the rate of change in TFP. In order to hold the rate of return to capital constant, $w_k = 0$, the rate of change in output prices must satisfy

$$\sum_i m_i p_i = \sum_{j \neq k} s_j w_j - tfp \quad (7)$$

which can be written in the familiar form

$$(\Delta P / P) = (\Delta PI / PI) - X \quad (8)$$

or, the proportional change in output prices is equal to the proportional change in an input price index less a productivity factor, X . Thus, price regulation with the appropriate input price index and productivity factor can duplicate the price changes realized under (constant) rate of return regulation.

Futhermore, Caves and Christensen developed a theoretical breakdown of TFP into components related to output, network, utilization, and technological effects. Applying this to telecommunications, Christensen, et al, (1994) show that (1) can be rewritten as

$$tfp = \sum_i (m_i - e_i) y_i - e_n n + v \quad (9)$$

where e_i is the cost elasticity of output i , e_n is the cost elasticity of network size, n is the network growth rate, and v is the rate of technological change. This allows a decomposition of the TFP growth estimates into scale, density, and technical change effects. Economies of scale exist if the sum of the cost elasticities of ouput and network growth rates is less than one

($\sum_i e_i + e_n < 1$). When economies of density are present, the output cost elasticities sum to less than one ($\sum_i e_i < 1$). The net effect of output growth on TFP growth is greater, the greater the

disparity between the revenue and cost elasticities for each output, holding constant the rates of network growth and technological change.

Calculating the TFP Growth Rate

In the equations of the last section, the growth rates of outputs, inputs, and TFP were expressed as instantaneous rates of change in Divisia index form. The data available for calculating measures of these growth rates, however, are discrete and yield discrete rates of change. To account for this disparity, Tornqvist transformations of the discrete data are used to approximate the instantaneous Divisia indices (Diewert; Denny, Fuss, and Waverman). In this form, Equation (1) becomes

$$tfp_t = \left(\sum_i 1/2(m_{it} + m_{it-1}) \ln(Y_{it} / Y_{it-1}) \right) - \left(\sum_j 1/2(s_{jt} + s_{jt-1}) \ln(X_{jt} / X_{jt-1}) \right) \quad (10)$$

where Y is the quantity of output i, X the quantity of input j, and t indexes years.

To perform the calculations in (10), annual data on three outputs and three inputs were collected from annual reports for the years 1989 through 1993 submitted to the Tennessee Public Service Commission by 16 rate-of-return regulated local telephone companies. These companies range in size from less than 1300 to over 2.6 million access lines, although only two firms served more than 50,000 access lines during this period. The outputs are local telephone service, intraLATA toll and access services, and all other services, including residential “vertical” or “add-on” features such as call-waiting, and business services such as centrex and private lines. The inputs are labor, capital, and miscellaneous inputs.

The revenue measures used to compute the outputs’ revenue shares are total flat-rate and measured local service revenues, intraLATA toll and intrastate access revenues, and all other

revenues. The physical output measures are average access lines, intraLATA toll and intrastate access minutes, and undeflated revenues from other services. Revenue growth for the all other category is expected to reflect volume growth, since prices for the all other category were largely stable over this period. Alternatively, other revenues could have been deflated by a price index to approximate physical volumes, but lacking such a specialized index, this was judged as likely to introduce more errors than it corrected. Since prices in this category may have been reduced in response to competitive pressures (from PBXs or answering machines, for example), the resulting bias, if any, is to understate the rate of total output growth over this period.

The physical input measures are average employees, undeflated operating expenses except wages and benefits, and net plant in service. The expense figure for miscellaneous inputs could have been deflated by a price index to arrive at a quantity figure, but this was not done for fear of introducing additional errors. Also, the resulting TFP growth rate estimate is conservative, since using expense levels may overstate the true growth in inputs when input prices are rising and, thereby, understate the growth of TFP. Average net plant, roughly the historical dollar value of investment less accumulated depreciation, measures the capital input as an approximation to the rate base figure used to calculate capital costs under rate of return regulation. The TFP growth rate based on this capital measure will reflect the effect of TFP growth on capital expenses under traditional rate base/rate of return regulation.

Total costs were calculated as the sum of total operating expenses and capital costs as discussed below. Labor cost was calculated as total wages, salaries and benefits. Miscellaneous input costs were calculated as total operating expenses less wages, salaries and benefits. Capital costs were calculated by traditional rate of return regulatory methods as

$$CAP = [NP(ROR)(1 / (1 - T))] + D + OT$$

where NP is average net plant, ROR is the target rate of return granted in the Commission's most recent rate order for that company, T is the effective federal income tax rate, D is depreciation and amortization expense for the current year, and OT is other taxes. An alternative measure for capital costs was calculated as the simple difference between total revenue and total operating expenses, but the resulting TFP growth estimates were virtually identical to those using capital costs from the formula above.

The resulting TFP growth rates, expressed as percentages, are summarized in Table I. TFP growth rates are shown for each of the 16 companies for each year, as well as the average growth rate over the period for each company. The row labelled TOTAL shows the total TFP growth rate for each year calculated by summing the underlying data elements over companies and using these as inputs to equation (10). The row labelled SMALL shows the TFP growth rates for the 14 smaller companies by a similar calculation. South Central Bell (SCB), now known as BellSouth Telecommunications, dominates the TOTAL figures and serves over ten times as many customers as the next largest firm, United Telephone - Southeast (UTS) an affiliate of Sprint. UTS is over four times as large as the next largest firm in the sample. Each of the 14 small companies serves less than 50,000 access lines, with 10 serving less than 10,000 lines.

The yearly TFP growth figures vary widely from negative to positive in double digits. The largest swings are all for the smaller firms, for whom relatively small changes in numbers of outputs (revenues) or inputs (costs) may cause large proportional changes in TFP. Replacing a switch, for example, could double the net plant of the smallest firms. The larger firms, which cover larger areas, show less variation, but even the TOTAL figures vary from -3.6% to +18.5% from year to year. Nevertheless, the equivalent constant annual TFP growth rates for the period

are much more reasonable in size, ranging from -12.6% to +13.1% for the individual companies, with 4.2% for SCB. The equivalent constant TFP growth rate is 5.1% annually for TOTAL and 1.3% for the SMALL group.

The equivalent constant annual percentage change in the chain-weighted Gross Domestic Product Price Index (U.S. Dept. of Commerce) is 3.5% over this period, as shown at the bottom of Table I. The implied annual price changes for individual companies using equation (8) range from -8.6% to +16.1% compared to 1.6% for all companies as a group. Obviously, imposing the state level “generic” TFP growth rate on all companies would result in price changes widely divergent from those derived from the company-specific figures.

Table II compares the TOTAL figures in Table I to national and international telecommunications TFP growth rates for the post-divestiture period calculated by others. The Christensen, et al (1995), figures, the only other estimates to cover 1990-93, are calculated using data from the FCC on the inter- and intrastate regulated services of the seven Bell Regional Holding Companies and GTE. This high level of aggregation greatly reduces the variation in the TFP growth figures. These estimates are also smaller in size, with an equivalent constant annual rate of only 2.4% for the entire period and just under 3.0% for 1990-93. Crandall’s estimates for all U.S. telephone companies for 1984-88 are equivalent to a constant annual rate of 3.9% and show somewhat more variation, despite the even higher level of aggregation. Finally, the figures from Staranczak, et al, are averages over 10 OECD countries of TFP growth estimates, including their independent estimates for some countries and previously published estimates for others. Although some of their individual country estimates nearly reach double-digits in individual years (9.9% for Japan 1985, 8.4% for Australia 1987), the range of individual

country averages (1.4% to 5.8%) and the equivalent annual rate for the period (4.0%) are similar to Crandall's figures.

In sum, the TOTAL Tennessee TFP growth rate is somewhat higher than similar figures calculated by others for more highly aggregated company groupings, but not unreasonably so. Nevertheless, the 18.5% estimate for 1993 suggests an extension of the sample period to determine whether this is evidence of an increasing trend or just an unusual single year. This is the subject of additional research in progress.

The application of a price regulation formula, such as equation (8), in Tennessee using the figures in Table I could have produced overall price decreases of about 1.6% annually over this period, comparing favorably with rate of return regulation. Obviously, the results would have varied greatly from company to company. Nevertheless, the formula recently adopted in legislation in Tennessee (Tennessee General Assembly), limits overall price increases to the annual percentage change in the GDP-PI less 2%, or one-half the annual percentage change in GDP-PI, whichever is less. This formula would have produced price increases of 0.8% to 2.1% annually over this period. Similarly, the productivity (X) factors adopted in Delaware (3.0%), New Jersey (2.0%), North Dakota (2.75%), Pennsylvania (2.93%), Rhode Island (3.0%), and Wisconsin (3.0% +/- 2.0% incentive/penalty) all fall short of the constant annual Tennessee TFP growth rate estimated over this period, with only California (Pacific Bell 4.5%, GTE 5.0%), Illinois (4.3%) and Oregon (4.0%) coming close (Davis). Perhaps, however, this partially explains the Tier 1 local telephone companies (the Bell regional holding companies and GTE) selection of the highest productivity factor (5.3%) under the FCC's price regulation for the interstate services of local exchange carriers (Telecommunications Reports).

Nevertheless, as competition develops, price differences due to the variations in price cap formulas should be reduced and eventually eliminated by competitive forces. Short-run underestimation of the productivity factor will not cause long-run price distortions if the onset of price regulation is paired with the elimination of regulatory barriers to entry. On the other hand, initial adoption of productivity offsets that are “too high” may discourage entry, delaying the benefits of competition even if barriers are simultaneously removed, while perpetuating regulatory price distortions.

Scale and Density Effects in TFP Growth

Here, using equation (9), the scale and density effects contained in the TFP growth estimates for Tennessee companies are decomposed by estimating a regression equation of the form:

$$tfp = a + b_1PDLINES + b_2PDMINUTES + b_3PDOTHER + b_4PDPLANT + \varepsilon$$

where PDLINES is the annual percentage change in access lines, PDMINUTES is the annual percentage change in toll and access minutes, PDOTHER is the annual percentage change in other revenues and PDPLANT is the annual percentage change in net plant. The first three variables are the changes in the output quantities, while PDPLANT represents the change in network size as shown in (9). Lacking a measure of technological change, the residuals of this equation are taken to include the effects of technological change along with the usual error term.¹

Ordinary least squares estimation of this equation yields the results shown in Table 3. The parameter estimates are all highly significant, with the exception of the intercept, as is the regression equation. The R-square indicates that over 60% of the variation in TFP growth is

explained by effects other than technological change. Indirect measures of technological change were rejected for producing perverse results. A simple time-trend and annual central-office expenditures per access line, for example, were significant at the 10% level but with oddly negative signs. In other unreported regressions, measures of scale or size were resoundingly insignificant, including number of access lines and value of net plant in both nominal and log forms, as were dummy variables for the large companies both individually and grouped. Regression of the residuals of the equation reported in Table 3 against all of the possible explanatory variables yielded insignificant results, indicating absence of heteroscedasticity.

The individual parameter estimates indicate the effect on TFP percentage growth rates by percentage changes in the three outputs and network size/net plant. Since the output coefficients are all positive, the revenue effects of output growth exceed the cost effects, holding network “size” or investment fixed. A 10% increase in access lines, for example, increases TFP growth by about 2.2 percentage points. Similarly, a 10% increase in toll and access minutes raises TFP growth by 3.6 percentage points, while a 10% increase in other outputs increases TFP growth by 0.62 percentage points. Increases in network size or investment reduce TFP growth, holding output constant.

As shown in Table IV, the scale effect is approximately 0.76, indicating increasing returns to scale: a 1% increase in all outputs and network size produces an increase in cost of 0.76%. The density effect is approximately 0.36, well less than one, indicating economies of density: if all outputs increase by 1%, holding network size constant, then cost increases by 0.36%. Other estimates of scale and density effects in the production of telecommunications services come to similar conclusions. The cost studies reviewed by Waverman, and those performed by Shin and Ying, find support for economies of density, with close to constant

returns to scale, although Shin and Ying lack a good measure of network size. An econometric study of TFP growth by Bellcore (1987) found constant returns to scale, and a density effect of 0.8. Other econometric studies that lack measures of network size (Kwoka; Crandall and Galst; Staranczak, et al) find density effects ranging from 0.34 to 0.76. Gasmi, Laffont, and Sharkey's (1995) analysis of pseudo-data generated by the LECOM engineering process model (Gabel and Kennet) with a single output (call seconds) and a fixed network size (120,000 customers in 150 square kilometers) found a "scale" cost elasticity, what we call the density effect, of 0.30. Garrone (1996) finds that scale economies are exhausted in the neighborhood of 10 million access lines, with no economies of density, using data for nine European countries over 1980-1992.

With the possible exception of Shin and Ying, all of these studies use data on companies or operations that are much larger than those examined here. This may explain the relatively large estimate of scale economies present in this sample: the relatively small size of the Tennessee operations may not allow the capture of all the benefits of scale and/or scope in local telecommunications.

Conclusion

Total factor productivity growth, on a rate of return comparable basis, was equivalent to a constant annual rate of 5.1% for 16 regulated local exchange telephone companies in Tennessee over the 1989-93 period. This productivity growth exceeded the equivalent growth in GDP-PI by 1.6 percentage points. Nevertheless, there was considerable variation in the TFP growth rates across individual companies and years, especially among the smaller companies. Although the absolute size of the average Tennessee TFP growth rate for the period exceeded recent estimates

of TFP growth for more aggregated samples, the difference was not unreasonable. The year-to-year variation in the Tennessee estimates, however, was somewhat larger than that in the more aggregated samples.

Decomposition of the TFP growth rates for Tennessee companies by means of regression analysis, indicates economies associated with density, or increases in output for a given network “size”, and mildly increasing returns to scale. These results are comparable to those reported in the existing literature for other samples. Nevertheless, the regression results suggest that over 60% of the variation in TFP growth rates in Tennessee is due to these scale and density effects, not technological change.

These results also suggest the reasons behind telephone company support for “price regulation” over traditional rate base/rate of return regulation. The productivity offsets and price indexes adopted in most states, including Tennessee, appear to allow price increases when price cuts are appropriate. The Tennessee TFP growth estimates are conservative due to the choices made in the construction of the output and input growth components. The “true” growth rates may be even higher.

Fortunately, the future provides a living laboratory for further research on the actual effects of price regulation in practice. Enforcement of the price cap requires the computation of price indices which will allow more precise estimates of output quantity changes. As long as regulators continue to collect input, cost, and revenue data on an annual basis, improved TFP growth rate estimates at the state level should be possible.

Nevertheless, initial “mistakes” in the choice of the productivity offset may be mitigated by growth in competition, when entry barriers are reduced or eliminated simultaneously with the adoption of price regulation. The estimated scale economies in this sample, however, suggest

that one traditional wire-line local telephone company may be more efficient than rivals using the same technology in markets of small to modest size. In this case, new technologies, such as coaxial cable and PCS/PCN wireless systems, may be the only economical route for significant entry and competition in small, or geographically less dense, service areas.

References

- Bell Communications Research. 1987. "Econometric Estimation of the Marginal Operating Cost of Intrastate Access," Special Report SR-FAD-000552.
- Caves, Douglas and Laurits Christensen. 1988. "The Importance of Scale, Capacity Utilization, and Density in Explaining Interindustry Differences in Productivity Growth," *The Logistics and Transportation Review*, March, pp. 3-32.
- Christensen, Laurits R., Philip E. Schoech, and Mark E. Meitzen. 1994. "Productivity of the Local Operating Telephone Companies Subject to Price Regulation," Prepared for the United States Telephone Association, Federal Communications Commission CC Docket No. 94-1, May 3.
- _____. 1995. "Productivity of the Local Operating Telephone Companies Subject to Price Regulation, 1993 Update," Prepared for the United States Telephone Association, Federal Communications Commission CC Docket No. 94-1, January 16.
- Crandall, Robert W. 1991. "Telephone Services and Rates," Chapter 3 of *After the Breakup: U.S. Telecommunications in a More Competitive Era*, Washington: Brookings.
- Crandall, Robert W. and Jonathan Galst. 1991. "Productivity Growth in the U. S. Telecommunications Sector: The Impact of the AT&T Divestiture," Washington: Brookings.
- Davis, Vivian W. 1995. "Breaking Away from Franchises and Rate Cases: A Perspective on the Evolution of State Telecommunications Policy," National Regulatory Research Institute, Columbus, OH, February.
- Denny, M., M. Fuss and L. Waverman. 1981. "The Measurement and Interpretation of Total Factor Productivity in Regulated Industries, with an Application to Canadian Telecommunications," in T. Cowing and R. Stevenson, eds., *Productivity Measurement in Regulated Industries*, New York: Academic Press.
- Diewert, W. E. 1976. "Exact and Superlative Index Numbers," *Journal of Econometrics*, v.4 n. 2.
- Gabel, D. and M. Kennet. 1991. "Estimating the Cost Structure of the Local Exchange," Report No. 91-16, National Regulatory Research Institute, Columbus, OH.
- Garrone, Paola. 1996. "Network Subscription and Services Usage in European Telecommunications Industries," *Information Economics and Policy*, v. 8 n. 1, March.
- Gasmi, Farid, Jean-Jacques Laffont and William Sharkey. 1995. "Incentive Regulation and the Cost Structure of the Local Telephone Exchange Network," PUR/IDEI/CIRANO

Conference on “The Transition Towards Competition in the Network Industries,”
Montreal, October.

Kmenta, Jan. 1971. *Elements of Econometrics*, New York: Macmillan.

Kwoka, John. 1993. “The Effects of Divestiture, Privatization, and Competition on Productivity in U.S. and U.K. Telecommunications,” *The Review of Industrial Organization*, May, pp. 47-62.

Shin, Richard and John Ying. 1992. “Unnatural Monopolies in Local Telephone,” *Rand Journal of Economics*, Summer, pp. 171-183.

_____. 1993. “Costly Gains to Breaking Up: LECs and the Baby Bells,” *Review of Economics and Statistics*, May, pp. 357-361.

Staranczak, Genio A., Edgardo R. Sepulveda, Peter A. Dilworth and Shafi A. Shaikh. 1994. “Industry Structure, Productivity and International Competitiveness: The Case of Telecommunications,” *Information Economics and Policy*, 6, pp. 121-142.

Telecommunications Reports. 1995. “FCC Alters Price Cap Plan for LECs; Changes Will Lead to Access Rate Decrease,” April 3, pp. 1-4.

Tennessee General Assembly. 1995 “Chapter 408 of the Public Acts of 1995,” Nashville, TN.

Waverman, Leonard. 1989. “U.S. Interexchange Competition,” in R.W. Crandal and K. Flamm, eds., *Changing the Rules: Technological Change, International Competition, and Regulation in Communications*, Washington: Brookings.

TABLE I

Annual Percentage Change in TFP and GDP-PI
and Four-Year Constant Annual Growth Rate Equivalent*
16 Tennessee Companies
1990-1993

<u>Company</u>	<u>1990</u>	<u>1991</u>	<u>1992</u>	<u>1993</u>	<u>Annual Rate</u>	<u>Implied Annual Price Change**</u>
ADA	11.6	-3.7	5.9	-2.1	2.9	+0.6
ALL	35.4	-41.7	19.4	12.2	1.4	+2.1
ARD	-3.3	-6.0	4.8	-10.6	-3.7	+7.2
CLA	13.8	-0.5	4.2	-0.1	4.2	-0.7
CON	-10.2	-12.6	17.5	-8.3	-4.1	+7.6
CRO	7.6	2.1	3.4	39.2	12.1	-8.6
LOR	-5.7	3.2	-4.9	0.5	-1.3	+4.8
MIL	-8.3	-8.6	25.8	38.9	10.0	-6.5
OOL	0.5	-21.4	3.4	11.1	-2.4	+5.9
PEO	6.7	3.6	2.5	-4.7	1.9	+1.6
SCB	-1.2	-3.4	5.6	17.7	4.2	-0.7
TEL	-5.0	-37.1	-4.7	2.3	-12.6	+16.1
TEN	2.1	-21.0	4.5	-2.6	-4.8	+8.3
UNI	17.2	6.9	8.4	1.1	8.2	-4.7
UTS	7.3	1.4	7.9	23.6	9.8	-6.3
WEST	0.8	-24.6	-0.5	5.2	-5.6	+9.1
TOTAL (16)	0.02	-3.6	6.9	18.5	5.1	-1.6
SMALL (14)	2.7	-14.5	10.2	9.0	1.3	+2.2
GDP-PI	4.2	4.0	3.1	2.8	3.5	

* Constant Annual Rate = $\{ \exp [(1/4) \ln \{ (1+tfp_1)(1+tfp_2)(1+tfp_3)(1+tfp_4) \}] \} - 1$

** Constant annual rate of change in GDP-PI less constant annual rate of TFP growth.

TABLE II
 Comparison of Telecommunications TFP Growth Estimates
 1984-1993
 (%)

<u>Year</u>	<u>Tennessee</u>	<u>Christensen</u>	<u>Crandall</u>	<u>Staranczak</u>
1984	n.a.	n.a.	1.6	3.1
1985	n.a.	1.1	0.6	4.4
1986	n.a.	2.8	5.4	3.6
1987	n.a.	1.8	8.2	5.0
1988	n.a.	2.1	3.8	n.a.
1989	n.a.	2.0	n.a.	n.a.
1990	0.02	4.6	n.a.	n.a.
1991	-3.6	1.2	n.a.	n.a.
1992	6.9	3.5	n.a.	n.a.
1993	18.5	2.6	n.a.	n.a.
Annual Rate	5.1	2.4	3.9	4.0

TABLE III
Regression Results: Dependent Variable TFP Growth

<u>Variable</u>	<u>Coefficient</u>	<u>t-statistic</u>
Intercept	-0.0211	-1.606
PDLINES	0.2193	5.565*
PDMINUTES	0.3621	5.601*
PDOTHER	0.0619	6.373*
PDPLANT	-0.4025	-5.692*
N: 64	Adj. R-square: 0.6422	F-statistic: 32.862*

*significant at the 0.01 level or better.

TABLE IV

Cost Elasticities, and Density and Scale Effects
at Sample Mean Revenue Shares***

	<u>Revenue Shares</u>	<u>Coefficient</u>	<u>Cost Elasticities*</u>
Local Service	0.518	0.2193	0.2987
Toll & Access	0.411	0.3621	0.0489
Other	0.071	0.0619	<u>0.0091</u>
Density Effect**			0.3567
Network		-0.4025	<u>0.4025</u>
Scale Effect**			0.7592

* Revenue Share less corresponding regression coefficient ($m_i - b_i$).

** Density effect is the sum of the cost elasticities ($\sum e_i$); Scale effect is the density effect plus the network cost elasticity, the negative of the regression coefficient on PDPLANT, ($\sum e_i + e_n$).

*** The density and scale effects at the sample minimum and the sample maximum are virtually identical to those reported here.

¹ / The estimates of the regression parameters when a relevant variable is omitted will be biased and inconsistent for included variables that are correlated with the omitted variable. If the included variables are not correlated with the omitted variable, then only the intercept estimate is biased, but the estimated variances of the other estimated parameters may be biased upward. This means that statistical tests of the significance of the estimated coefficients may be biased toward accepting the null hypotheses that the coefficients are equal to zero (Kmenta).

The latter problem does not appear to be serious in this regression, since all the estimated coefficients are highly significant. To get a handle on the former, regressions were run using a simple trend or annual central office expenditures as proxies for technological change. In both cases, the estimated coefficients were negative and marginally significant, suggesting the perverse outcome that technological change reduced productivity. The coefficient on the net plant variable was substantially reduced in magnitude, but not significance, by the introduction of the c-o expenditure variable, which is a component of the net plant calculation. No clear indication of the effect of omitting technological change from the regression was apparent from these results.

Note that by the end of the sample period, all of these companies had fully digital central offices and were beginning the installation of improvements to offer ISDN over their networks. Data on these changes were not available for most of the sample at the time the other data were assembled.