requirements of the methodology are met with company records and, in fact, most of the required data are filed annually with the Federal Communications Commission.

To measure total output, seven different types of services are distinguished: local service, interstate end user access, interstate switched access, interstate special access, intrastate access, long distance service, and miscellaneous services. Price changes are factored out of each category's revenues to obtain quantity indexes. The quantity indexes for the revenue categories are aggregated into an overall output quantity index.

The weights used in the computation of the output index are the revenue shares of the services contained in the index. For purposes of determining the productivity offset in a price cap formula, this is the proper specification for the output index. By employing the revenue weighted output index, prices paid by LEC customers can be linked to changes in input price inflation and changes in TFP.[5] Proper specification of the output index is important because changes in output growth are directly related to changes in TFP growth.[6]

Total input is comprised of capital (plant and equipment), labor, and materials (purchased materials, rents, and services). To construct a quantity index of total input, we first construct separate quantity indexes for capital, labor, and materials.

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[5]This relationship is formally presented in Appendix 1.

[6]Chapter 2 explores in detail the relationship between output growth and TFP growth.

The capital, labor, and materials quantity indexes are then aggregated into an overall input quantity index with cost shares serving as the weights for the input categories.

To measure capital input, six asset classes are distinguished: buildings, general support equipment, central office equipment (including operator systems), transmission equipment, information origination/termination equipment, and cable and wire. Quantity indexes and annualized costs are calculated for each of the asset classes; then an overall quantity index of total capital input is computed from the asset classes, with their cost shares used as weights.

Labor input is the time spent by LEC employees in providing services to LEC customers. It does not include the time spent installing plant and equipment, since this time is included in the capital input measure. Two groups of employees are distinguished in the study: management and non-management. The quantity index of labor input is an index of management and non-management hours worked, with management and non-management labor cost shares used as weights.

The cost of materials is equal to total operating expense less depreciation and payments to labor. Since this category is comprised of a diverse set of inputs, the U.S. Gross Domestic Product Price Index (GDPPI) is used to represent the price of materials. The quantity index of materials is obtained by dividing materials cost by its price.

Chapter 2 provides the theoretical framework for analyzing sources of TFP growth and reviews empirical studies of TFP growth in the telephone industry. A primary

source of TFP growth in the telephone industry is output growth. Furthermore, services that have relatively high levels of contribution to joint and common costs (i.e., low marginal costs relative to price) have relatively greater contributions to TFP growth. Two service groups with relatively high contribution margins are also areas that will be facing increased competition in the future--intra-LATA toll and switched access. As competition increases in these services, LECs are faced with the prospect that future output growth in these areas will be less than historical growth, leading to downward pressure on TFP growth.

Chapter 1
Total Factor Productivity Study

In this chapter, we describe the methods used to calculate total output (Section 1.1), and total input (Section 1.2). In Section 1.3 we present the annual figures for total output, total input, and Total Factor Productivity. Most of the data used in the computations come either from the Form M annual reports filed with the FCC or were supplied to us directly by the LECs. We have reviewed all data to ensure that they are reasonable and appropriate.

1.1 Total Output--Methods

The Local Exchange Carriers provide a variety of telecommunications services; consequently LEC output cannot be adequately measured using simple physical indicators such as access lines, number of calls, or minutes of use. To properly measure output, different types of LEC services must be distinguished, and for each service category, price and quantity indexes must be developed that accurately represent the complexity and diversity of telephone operations. We measure seven major categories of services: local service, interstate end user access, interstate switched access, interstate special access, intrastate access, long distance service, and miscellaneous services. For each of these service categories, a price index is constructed to represent price changes that occurred during the study period. The price indexes are used to factor price changes out of each service category's revenues, yielding an output quantity index for each service category.

Output by Category

The company Form M annual reports show booked revenue for each of the service categories listed above. When using these data, it is important to make adjustments for changes in accounting definitions. In particular, the mandated accounting revisions in 1988 must be addressed.[1] The primary difference between reported operating revenue through 1987 and reported operating revenue beginning in 1988 is revenue from certain nonregulated services. Beginning in 1988, all revenue from nonregulated services that had joint and common costs with regulated services were reported in operating revenue. Before 1988 this was not the case. The LECs provided Christensen Associates with adjustments to the Form M booked revenues for the 1984-1987 period in order to put revenues from the two periods (1984-1987 and 1988-1992) on a consistent accounting basis. These adjustments apply to the miscellaneous services category.

Price indexes for local service, intrastate access, and long distance service are constructed from the price change information reported by the LECs in the Form M.[2] In the Form M, the LECs report the impact of rate changes in terms of changes in revenue. The methodology we use converts the dollar change in revenue to a percentage change in the overall rate level. These percentage changes in rate levels

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[1]This is the Uniform System of Accounts Rewrite, or USOAR, which was mandated by the FCC and implemented in 1988.

[2]Form M price change information was available for Ameritech, Bell Atlantic, Bell South, NYNEX, Pacific Telesis, Southern New England, Southwestern Bell, and U S West. This information was used to construct the price indexes for local, intrastate access, and long distance service in this study.

are then used to construct a price index. Appendix 2 of this report provides a detailed description of this methodology.

Because the interstate access rate change information filed in the Form M is not as comprehensive as the information filed by the companies for intrastate price changes, other methods are used to construct price indexes for interstate end user access, interstate switched access, and interstate special access. The price index for interstate end user access is computed as the ratio of end user access revenue to the number of access lines, where both revenue and access lines are taken from the Form M report. To compute a price index for interstate switched access, a quantity index is first computed. This quantity index is a Tornqvist[3] index of LEC common line minutes of use and traffic sensitive minutes of use, where carrier common line and traffic sensitive revenues are used as weights. Once the quantity index is computed, the price index is obtained by dividing booked revenue by the quantity index. Finally, a special access price index is developed from LEC data on prices for special access services.

For local service, interstate end user access, interstate switched access, and interstate special access, the quantity indexes are obtained by dividing booked revenue by the corresponding price index. For intrastate access and long distance service, a different approach is necessary. The reason is that the price indexes represent the prices paid by customers, while the revenue represents the revenue

[3]The Tornqvist index determines the rate of growth of a quantity index by weighting the growth of each of the services in the index by each service's revenue share.

received by the companies. Because of the settlements process, the revenue received by the company does not equal the amount paid by the customer. Consequently, we obtain quantity indexes for these services by dividing billed revenue by the corresponding price index.[4]

Since miscellaneous services represents a wide variety of activities, the U.S. Gross Domestic Product Price Index (GDPPI) is used as the price index for this category. The quantity index for miscellaneous services is obtained by dividing adjusted booked revenue by the GDPPI.

Total Output

The quantity indexes for the revenue categories are aggregated using the Tornqvist index. The index produces an overall rate of growth in total output by weighting the growth rates for each revenue category. The weights used in the computation are the revenue shares of the categories, where the adjusted revenues described above are used in constructing the weights.

1.2 Total Input--Methods

Total input is comprised of capital (plant and equipment), labor, and materials, rents, and services (hereafter referred to as materials). To construct a quantity index of total input, quantity indexes for capital, labor, and materials are constructed. The

[4]As noted above, the price index for interstate access is constructed using booked revenues. In this case, revenue and price indexes both represent the revenue received by the companies.

capital, labor, and materials quantity indexes are then aggregated using the Tornqvist index to obtain the quantity index of total input, with cost shares serving as the weights for the various categories.

Capital

The quantity and cost of capital input is based on the Christensen-Jorgenson methodology[5]. Six asset classes are distinguished: buildings, general support equipment, central office equipment (including operator systems), transmission equipment, information origination/termination equipment, and cable and wire. The quantity of capital stock is calculated for each asset class using the perpetual inventory capital stock equation, which has the form:

$$K_t = (1 - \delta)\cdot K_{t-1} + I_t \qquad (1.1)$$

where

K_t = the quantity of capital stock at the end of year t
I_t = the quantity of investment during year t
δ = the economic rate of replacement.

The economic rates of replacement used in the study are taken from Jorgenson.[6] The rates are: 15.5% for general support equipment, 11.0% for central office equipment, transmission equipment, and information origination/termination

[5]See Christensen and Jorgenson, 1969.

[6]D.W. Jorgenson, "Productivity and Economic Growth," in E.R. Berndt and J.E. Triplett, eds., Fifty Years of Economic Measurement (Chicago: University of Chicago Press, 1990), pp. 19-118.

equipment, and 2.3% for buildings and cable and wire. The quantities of investment are obtained by dividing the value of investment by the corresponding investment price deflators, also known as Telephone Plant Indexes. The LECs provided Telephone Plant Indexes for each of the asset classes, for each year. The values of additions to plant are based on data reported in the Form M, which need to be adjusted for the USOAR accounting changes. The primary accounting change affecting the measurement of capital occurs in 1988. Starting in 1988, some expenditures that had previously been reported as additions to plant were now required to be reported as operating expense. In 1988, operating expense for the LECs increased by $2.1 billion because of these accounting changes. This figure was used as the basis for adjusting reported gross additions for the 1984-1987 period.

A starting value, or benchmark, for K must be calculated in order to apply the perpetual inventory capital stock equation. We calculate a 1984 benchmark for each asset class, based on the 1984 replacement cost as provided by the LECs. This 1984 replacement cost is a "current cost of gross plant" measure. That is, assets of different vintages are repriced to provide a common basis of valuation. It is necessary to adjust the replacement cost for the age distribution of the assets. The U.S. Bureau of Economic Analysis reports the age distribution of the relevant assets for the telecommunications industry. This industry age distribution of plant and equipment is used to derive the LEC age distribution of plant and equipment. The LEC age distribution is then used to obtain a benchmark value for each asset class. Finally, an

adjustment for USOAR is also necessary for the benchmark, since the data underlying the benchmark estimate are based on the pre-USOAR accounting standards.[7]

Once the quantity indexes are computed for each of the asset classes, they must be aggregated into an overall capital input index. The weights used to aggregate the asset classes are the annual capital costs of each asset class (also referred to as the "implicit rental" costs). The annual cost of capital services for each asset class is calculated using the Christensen-Jorgenson methodology and includes four components: (1) the opportunity cost of the capital held in the form of plant and equipment; (2) plus cost of declines in efficiency of plant and equipment; (3) less the economic revaluation of plant and equipment; (4) plus the cost of property taxes and profits taxes.[8]

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[7]There is one caveat with respect to the 1984 benchmarks used in the study. The 1984 replacement cost for information origination/termination equipment includes some inside wire. Although inside wire maintenance was deregulated, the companies had not recovered the original cost of inside wire in place at the beginning of 1984. In order to recover the remaining cost of the inside wire, it was included in the rate base, and consequently in the plant and equipment reported in the Form M. Because inside wire was included in plant and equipment solely for cost recovery purposes, it is appropriate to exclude it from the TFP study. Accurate identification of the replacement cost of the inside wire was not possible. To approximate the impact of removing inside wire, we recalculated TFP growth based on the assumption that information origination/termination equipment grows at the same rate as the other plant and equipment categories. This recalculation results in annual average TFP growth of approximately 2.2 percent, yielding a TFP growth differential between the LECs and the private business sector of approximately 1.3 percent. Thus, the results reported in Table 1, which are based on not adjusting for inside wire, indicate higher TFP growth than if we had adjusted for inside wire.

[8]See Christensen and Jorgenson, 1969. The Christensen-Jorgenson formula for the implicit rental price is:

$$v_t = [(1 - u \cdot z - k)/(1-u)] \cdot [r_t \cdot p_{t-1} + \delta \cdot p_t - (p_t - p_{t-1})] + \tau \cdot p_t ,$$

For each of the asset classes, the four components of annual capital costs are calculated as follows. First, the opportunity cost of the capital held in the form of plant and equipment is calculated by multiplying the current economic value of plant and equipment by the appropriate interest rate. The current economic value of plant and equipment is obtained by multiplying the quantity of the capital stock by the relevant Telephone Plant Index. The interest rate used as the opportunity cost is Moody's Composite Yield on Public Utility Bonds. Second, the cost of declines in efficiency is obtained by multiplying the economic rates of efficiency decline by the current economic value of plant and equipment. Third, the economic revaluation of plant and equipment is obtained by multiplying the quantity of capital stock by the change in the relevant Telephone Plant Index. Fourth, the cost of property and profits taxes is based on taxes reported in the Form M.

Once the quantity indexes and costs are calculated for each of the asset classes, the quantity index of total capital input is computed as a Tornqvist index of the asset classes, with their capital service costs as weights. The total cost of capital input is equal to the sum of the costs for the six asset classes.

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where u is the rate of taxation on income, z is the present value of tax depreciation allowances, k is the investment tax credit rate, r is the interest rate (Moody's yield on public utility bonds), p is the Telephone Plant Index, δ is the rate of economic replacement (representing the declines in efficiency), and τ is the rate of property taxation. The income tax rate, the property tax rate, and the investment tax credit rate are based on income taxes, property taxes, and investment tax credits reported by the LECs in the Form M report. The present values of tax depreciation allowances are based on the tax lifetimes and depreciation formulas specified by law.

Labor

Labor input includes the time spent by LEC employees in providing services to LEC customers. It does not include the time installing plant and equipment, since this input is included in the capital input measure. Two groups of employees are distinguished in the TFP study: management and non-management.

The cost of labor input is equal to expensed wages and salaries plus expensed benefits. The total cost of labor is reported in the Form M report. The LECs provided us with a breakdown of labor costs into management and non-management labor costs. The LECs also provided to us total management hours worked and non-management hours worked. The quantity index of labor input is a Tornqvist index of management and non-management hours worked, with management and non-management labor costs used as weights.

Materials, Rents, and Services (Materials)

The cost of materials is equal to total operating expense less depreciation and payments to labor. This information is reported in the Form M. Since the materials data are based on data filed in the Form M, adjustments must be made for the USOAR accounting changes. The two major changes affecting materials are the treatment of nonregulated activities (discussed in our previous section on output) and the shifting of expenditures from the plant and equipment account to the operating expense account (discussed in our previous section on capital input). The LECs provided us the necessary adjustment figures. The Gross Domestic Product Price Index is used

to represent the price of materials, since this category is comprised of a diverse set of inputs. The quantity index of materials is obtained by dividing materials cost by its price.

1.3 Total Output, Total Input, and Total Factor Productivity--Results

The index of TFP is computed as the ratio of the quantity index of total output to the quantity index of total input. Equivalently, the rate of growth of TFP is computed as the rate of growth of the quantity index of total output minus the rate of growth of the quantity index of total input.

Table 1 shows the quantity index of total output, the quantity index of total input, and the TFP index. Also shown are the annual rates of growth in total output, total input, and TFP. Over the 1984-1992 period, total output grew at an average annual rate of 3.5 percent,[9] total input grew at an average annual rate of 0.9 percent, and TFP grew at an average annual rate of 2.6 percent.[10]

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[9]All percent growth rates that we report are computed using natural logarithms. For example, for the average annual growth of output between 1984-1992, 3.5% = ((ln 1.322 - ln 1.000)/8) x 100.

[10]A sensitivity analysis was performed to assess the impact on the TFP results of our adjustments for the accounting changes regarding non-regulated revenues and expenses, and the shifting of expenditures from capital to expense accounts. Failure to adjust for non-regulated revenues and expenses has no material impact on the results. Failure to adjust for the capital to expense shift would lower average annual TFP growth over the study period to 2.3 percent. Based on an average annual rate of growth for the private sector of 0.9 percent, the failure to adjust for the capital to expense shift lowers the TFP growth differential between the LECs and the private business sector to 1.4 percent.

Table 1

Local Exchange Carrier Total Factor Productivity

	Total Output Index	Total Output Growth Rate	Total Input Index	Total Input Growth Rate	TFP Index	TFP Growth Rate
1984	1.000		1.000		1.000	
1985	1.031	3.0%	1.012	1.2%	1.019	1.9%
1986	1.062	3.0%	1.015	0.3%	1.047	2.7%
1987	1.103	3.8%	1.033	1.8%	1.068	2.0%
1988	1.160	5.0%	1.065	3.0%	1.089	1.9%
1989	1.219	5.0%	1.094	2.7%	1.114	2.3%
1990	1.266	3.8%	1.086	-0.7%	1.165	4.5%
1991	1.295	2.3%	1.099	1.2%	1.178	1.1%
1992	1.322	2.1%	1.078	-1.9%	1.227	4.0%
Average Growth 1984-92		3.5%		0.9%		2.6%

Implications for Price Cap Productivity Offset. Conceptually, the productivity offset in the price cap formula is related to the differential in productivity growth achieved by the price cap local exchange carriers and the U.S. economy. The U.S. Bureau of Labor Statistics regularly publishes TFP growth for major sectors of the U.S. economy.[11] The most comprehensive TFP measure published by the Bureau of Labor Statistics is for the private business sector. Currently, the TFP index for the private business sector is available through 1990. The average annual rate of growth for the private business sector between 1984 and 1990 was 0.9 percent. Thus, the TFP growth differential between the LECs and the private business sector since divestiture has been 1.7 percent.

[11]The Bureau of Labor Statistics refers to its TFP measures as "multifactor" productivity. These measures are reported in the Bureau of Labor Statistics publication, Monthly Labor Review. The BLS does not currently publish multifactor productivity for the LECs.

Chapter 2
The Relationship Between Output Growth and Productivity Growth

2.1 Background

Total Factor Productivity (TFP) growth can arise from various sources. One primary source of TFP growth is technological change, shifts in the production function that allow a firm to use fewer inputs to produce the same amount of output. A second primary source of TFP growth is the exploitation of economies of density through output growth. Economies of density are present when average cost falls as more output is provided over a network of fixed size. Therefore, when economies of density are present, increases in output reduce the average level of inputs per unit of output. Consequently, increases in output growth lead to increases in TFP growth and, conversely, decreases in output growth lead to decreases in TFP growth.[12]

Prior to divestiture, the telephone industry experienced rapid rates of output growth, and econometric studies of the industry show that this output growth contributed significantly to TFP growth. Since divestiture, the Local Exchange Carriers (LECs) have experienced more modest rates of output growth, and with increasing competition in their markets, they face the prospect of even slower output growth. Because the provision of LEC services is characterized by economies of density, these reductions in output growth will tend to reduce LEC TFP growth.

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[12]Economies of scale and capacity utilization are other potential sources of TFP growth. Empirical studies have not found either to have a significant impact on TFP growth in the telephone industry.

In addition to the rate of growth in total output, the sources of that output growth can be an important determinant of TFP growth when economies of density are present. In industries with economies of density, prices are typically set above marginal cost for the various services provided by the firm, in order to generate revenue sufficient to cover total cost. When the markup of price relative to marginal cost varies over the services provided, growth in high markup services contributes more to TFP growth than growth in low markup services. Conversely, reductions in the growth of high markup services lead to disproportionate reductions in TFP growth. Much of the increasing competition for Local Exchange Carriers is focused in markets with high price-to-marginal-cost ratios. If competition effectively leads to lower LEC output growth in these high margin markets, LEC TFP growth will also be lower.

This chapter is organized as follows. Section 2.2 discusses in detail the theoretical relationship between economies of density, output growth, and TFP growth. Section 2.3 reviews the literature on economies of density in the telephone industry. We summarize the results of these econometric studies and report their implications for LEC TFP growth. Section 2.4 focuses on particular services provided by the LECs that are subject to emerging competition. These services have high price-to-marginal-cost ratios, and reductions in LEC output growth in these services will likely cause substantial reductions in LEC TFP growth.

2.2 Theoretical Framework

Douglas Caves and Laurits Christensen[13] developed a theoretical framework to analyze the relationship between output growth and TFP growth. Their framework is applicable to firms or industries that provide services over a network, such as the telephone industry. Other industries in which the network structure is important are the railroad, airline, trucking, and electric utility industries. TFP growth in such industries can be related to economies of density, economies of scale, capacity utilization, and technological change. Economies of density describe the change in average cost when more output is provided over a network of fixed size. For LECs, network size can be represented by measures such as the number of access lines. When average cost falls as output rises over this given network, economies of density are present. Economies of scale describe the change in average cost when both output and the size of the network increase. If average cost declines when output and network size increase proportionately, economies of scale are present. Capacity utilization describes the impact on cost when capital is not at its optimum level, i.e. the industry has too much or too little capital.

We use the Caves-Christensen model as a point of departure for exploring the relationship between output growth and LEC TFP growth. The analysis begins with the cost function. The cost function relates the total cost of inputs to the levels of

[13]"The Importance of Scale, Capacity Utilization, and Density in Explaining Interindustry Differences in Productivity Growth," The Logistics and Transportation Review, March 1988, pp. 3-32.

outputs, the levels of input prices, the size of the network over which the services are being provided, and the level of technology:[14]

$$C = C(Y,W,N,t) \tag{2.1}$$

where

C = total cost of inputs
Y = vector of output levels
W = vector of input prices
N = size of network
t = level of technology.

The rate of change in total cost can then be related to the rates of change in outputs, the rates of change in input prices, the rate of change in the network size, and the rate of technological change. Formally, the relationship is:

$$c = \Sigma\, \epsilon_i \cdot y_i + \Sigma\, s_j \cdot w_j + \epsilon_n \cdot n - v \tag{2.2}$$

where

c = rate of change in total cost
y_i = rate of change in output i
w_j = rate of change in input price j
n = rate of change in network size
v = rate of technological change
s_j = share of input j in total cost
ϵ_i = cost elasticity of output i
ϵ_n = cost elasticity of network size.

Next, the rate of change in total cost can be decomposed into the rate of change in input prices and the rate of change in input quantities:

[14]In the Caves and Christensen analysis, capacity utilization of quasi-fixed factors is also incorporated into the analysis. Because Caves and Christensen found that capacity utilization is not a determining factor in telephone TFP growth we have not included it in the model discussed in this report.

$$c = \Sigma s_j \cdot w_j + \Sigma s_j \cdot x_j \tag{2.3}$$

where

x_j = the rate of change in input quantity j.

Substituting equation (2.3) into equation (2.2) yields the following result:

$$\Sigma s_j \cdot x_j = \Sigma \epsilon_i \cdot y_i + \epsilon_n \cdot n - v \ . \tag{2.4}$$

The left-hand side of equation (2.4) represents the rate of growth in the quantity of total input. The rate of growth in the quantity of total input is related to the rate of growth in output, growth in network size, and the rate of technological change.

The rate of growth in total factor productivity is the difference between the rate of growth in total output and the rate of growth in total input. The definition of total output used in the TFP measure is based on a revenue weighted average of the rates of growth for the various outputs contained in the index. Thus, it is a "customer oriented" measure of TFP, since the revenue weights used in the output index represent the relative expenditures made by customers for the respective telecommunications services contained in the output index.[15] Moreover, this TFP index differs from estimates of "technological change" (shifts in the production function) that are derived from econometric models. The TFP index constructed in this analysis captures all sources of efficiency improvement--technological change,

[15]Appendix 1 discusses how TFP constructed with a revenue weighted output index allows one to relate output price changes to changes in input prices and changes in TFP.

economies of density, and economies of scale--and, therefore, is more relevant to the discussion of price caps than is an econometric analysis of technological change.

The rate of growth in TFP (the difference between the rate of growth in total output and the rate of growth in total input) can be related to output growth, growth in network size, and technological change via equation (2.4):

$$\begin{aligned} tfp &= \Sigma\, m_i \cdot y_i - \Sigma\, s_j \cdot x_j \\ &= \Sigma\, (m_i - \epsilon_i) \cdot y_i - \epsilon_n \cdot n + v \end{aligned} \tag{2.5}$$

where

tfp = rate of TFP growth

m_i = share of output i in total revenue.

Economies of density are present when the sum of the cost elasticities of output (the ϵ_i) are less than one; economies of scale are present when the sum of the cost elasticities of output and the network elasticity ($\Sigma\, \epsilon_i + \epsilon_n$) are less than one. When economies of scale or economies of density are present, increasing the level of output over the network increases TFP, because the revenue shares are larger than the cost elasticities ($\Sigma\, (m_i - \epsilon_i) > 0$). The contribution to TFP growth of each output depends on its growth rate and on the difference between its revenue share and its cost elasticity. As the difference between the revenue share and the cost elasticity increases, the contribution of output growth to TFP growth increases.[16]

[16]As discussed in Section 2.4, one must recognize that factors which historically led to TFP growth may not provide the same contribution in the future.

2.3 Review of Telecommunications Industry Econometric Studies

Caves and Christensen analyzed TFP growth in six industries: telephone, electric power, airline, railroad, urban bus, and trucking. They examined the contributions of economies of scale, economies of density, and capacity utilization to TFP growth in each industry. Their analysis of the telephone industry relied on the two major econometric studies of the U.S. telephone industry that had been completed at the time of their study.[17] Both these studies show a strong relationship between output growth and TFP growth. Though neither study includes measures of network size, Caves and Christensen concluded that the relationship between output growth and TFP growth was largely due to economies of density.

Two limitations of the studies on which Caves and Christensen rely are that neither study addresses the role of network size on TFP growth and both studies focus on the entire Bell System, which included both the Operating Companies and the Long Lines division. Bell Communications Research provided an econometric cost analysis in 1987 of the Bell Operating Companies that specifically addresses the issue of network size.[18] Using the methods developed by Christensen, Christensen, and

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[17]L.R. Christensen, D.C. Christensen, and P.E. Schoech, "Econometric Estimation of Scale Economies in Telecommunications," in L. Courville, A. de Fontenay, and R. Dobell, eds., Econometric Analysis of Telecommunications, (Amsterdam: North-Holland Press, 1983), and M.I. Nadiri and M.A. Schankerman, "The Structure of Production, Technological Change, and the Rate of Growth of Total Factor Productivity in the U.S. Bell System," in T. Cowing and R. Stevenson, eds., Productivity Measurement in Regulated Industries, (New York: Academic Press, 1981).

[18]"Econometric Estimation of the Marginal Operating Cost of Interstate Access," Special Report SR-FAD-000552, May 1987.

Schoech, Bellcore developed measures of output and input for the Bell Operating Companies, covering the years 1972 to 1982.[19] The econometric models estimated from these data include measures of network size. The estimated models show substantial economies of density, but constant returns to scale. This means that average cost decreases as output increases over a network of a given size, but average cost does not decrease when output and network size both increase at the same rate. The Bellcore results show that a one percent increase in output, holding network size fixed, leads to approximately a .8 percent increase in TFP.

In two recent papers, Richard Shin and John Ying have attempted to focus on local carriers and incorporate measures of network size. While there are some problems in the data used in both of these papers, their results indicate support for large economies of density. The first of these studies is based on data for 58 local telephone companies over the 1976-1983 period.[20] The output measures used in the study are number of local calls and number of toll calls, which fail to adequately capture the heterogeneity of services provided by local exchange companies. They characterize a third variable used in the analysis, number of access lines, as an output variable, but this variable characterizes the network over which services are being provided. The data also constrain Shin and Ying in the measurement of prices and

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[19]The database contained quarterly observations.

[20]"Unnatural Monopolies in Local Telephone," Rand Journal of Economics, Summer 1992, pp. 171-183.

quantities for the inputs. They assume quantity indexes for capital and for materials, rents, and services can be accurately represented by the number of access lines.

At the sample mean, the cost elasticities of local calls, toll calls, and access lines sum to .94, which shows minor economies of scale. However, the sum of the local call and toll call elasticities equals .25, which shows considerable economies of density. This would imply that a one percent increase in local and toll calls would increase TFP by .75 percent. The second Shin and Ying paper reports a similar analysis of 46 local carriers over the 1976-1987 period.[21] This paper has the same data limitations, and produces results similar to those of the first paper. Together, the two papers suffer from problems due to the data used, but their results are consistent with those of the other studies.

Two additional recent papers have used simpler econometric models in an attempt to directly relate telephone industry TFP growth to industry output growth. Neither study addresses the impact of network size. John Kwoka[22] analyzed the former Bell System companies over the 1948-1987 period. His econometric model relates TFP growth to output growth in addition to other structural variables. His model shows that a one percentage point increase in output leads to a

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[21] "Costly Gains to Breaking Up: LECs and the Baby Bells," Review of Economics and Statistics, May 1993, pp. 357-361.

[22] "The Effects of Divestiture, Privatization, and Competition on Productivity in U.S. and U.K. Telecommunications," The Review of Industrial Organization, May 1993, pp. 47-62.

.535 percentage point increase in TFP. Robert Crandall and Jonathan Galst[23] estimate an econometric model that similarly links TFP growth to output growth. They estimate this model for the former Bell System companies, independent local exchange carriers, and the entire telephone industry for the years 1961-1987. They find that a one percentage point increase in output increases TFP growth .34 percent for the former Bell System companies, .55 percent for the independent local exchange carriers, and .37 percent for the entire industry.

Finally, we briefly note a number of recent econometric studies based on the data developed by Christensen, Christensen, and Schoech. These studies have been conducted by David Evans and James Heckman;[24] A. Charnes, W.W. Cooper, and T. Sueyoshi;[25] and Lars-Hendrik Roller.[26] The authors have attempted to estimate models with multiple indexes of output, using the pre-divestiture Bell System data. None of the authors attempt to model network size. The results of these models vary

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[23]"Productivity Growth in the U.S. Telecommunications Sector: The Impact of the AT&T Divestiture," Brookings, February 1991.

[24]"Multiproduct Cost Function Estimates and Natural Monopoly Tests for the Bell System," in D.S. Evans, ed. Breaking Up Bell, North-Holland, New York, 1983; "A Test for Subadditivity of the Cost Function with an Application to the Bell System," American Economies Review, September 1984, pp. 615-623; "Natural Monopoly and the Bell System: Response to Charnes, Cooper, and Sueyoshi," Management Science, January 1988, pp. 27-38.

[25]"A Goal Programming/Constrained Regression Review of the Bell System Breakup," Management Science, January 1988, pp. 1-26.

[26]"Proper Quadratic Cost Functions with an Application to the Bell System," Review of Economics and Statistics, May 1990, pp. 202-210; "Modelling Cost Structure: the Bell System Revisited," Applied Economics, September 1990, pp. 1661-1674.