TECHNICAL CHANGE, MARKUP, DIVESTITURE, AND PRODUCTIVITY GROWTH IN THE U.S. TELECOMMUNICATIONS INDUSTRY

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Abstract—This paper examines the sources of productivity growth for the U.S. telecommunications industry from 1935 to 1987. These years encompass both the pre- and post-AT&T divestiture periods. We formulate a structural model that accounts for both changes in the cost and the demand side of the industry. We measure the contributions of aggregate demand, information intensity of the economy, price-cost margins, relative factor prices, direct and indirect effects of technological progress, and R&D investment on total-factor productivity (TFP) growth rate. We show that TFP growth rate as conventionally measured is a seriously biased measure of rate of technical change in this industry.

I. Introduction

In this paper, we examine the productivity performance of the U.S. telecommunications industry during the period 1935–1987. These years include both the pre- and post-AT&T divestiture periods. Previous studies on the subject have often been incomplete, emphasizing only supply-side factors as the primary determinants of productivity growth. This study focuses on the dynamic interplay between the demand and supply side of the industry and its impact on productivity.

We formulate a structural model that captures the dynamic interaction between the supply and demand sides of the market and then estimate that model. We then use the estimated parameters of the model to calculate the contribution of different sources to total factor productivity (TFP) growth rate in the U.S. telecommunications industry. Our study reveals that the conventional index of TFP growth rate does not always measure true shift in the technology. In the presence of nonconstant returns to scale and a nonmarginal cost-pricing policy, the conventional measure of TFP growth rate provides a biased estimate of the rate of technical change.

We decompose the conventionally measured TFP growth into separate components to identify distinct sources of productivity growth. The most important components are

i) changes in aggregate economic variables, such as aggregate income, population growth, and the growth of sector-specific information intensity;

ii) the movement of relative input prices;

iii) the direct and indirect impacts of autonomous technological progress; and

iv) the impact of market characteristics, such as the price-cost margin.

The analysis shows that productivity growth is more than a supply-side phenomenon. Demand-side factors also play a crucial role in determining productivity growth. The impact of industry demand on productivity growth is determined by analyzing the relationship among the growth of demand, the scale economies of production and the rate of technological change. The role of macroeconomic variables in influencing the productivity growth is also discussed. One of the conclusions of this study is that market size is of crucial importance to increase production efficiency.

We also analyze the behavior of price and the incremental cost of local and toll services, because this may reflect not only the changes in the production process but also possible interactions between market competition and the rate of technological change in the industry. Finally, we provide a detailed analysis of the changing behavior of the cost and demand sides of the industry over time under different market conditions and regulatory regimes, and then its impact on productivity. More specifically, the model analyzes the changing behavior of productivity due to regulatory activities, such as the introduction of competition in the long-distance service market and the 1984 divestiture of the Bell System.

The paper is organized as follows. Section II briefly states the econometric model used for empirical implementation. In Section III, the methodology for the decomposition of TFP growth is discussed. In Section IV, we present a summary of primary results obtained from the model estimation. The different sources of TFP growth are analyzed in section V, and the impact of divestiture on cost structure is discussed in section VI. Concluding remarks are stated in the last section.

II. Econometric Model Specification

The traditional measure of TFP growth, based on the Divisia index formula, assumes that producers are in long-run equilibrium, technology exhibits constant returns to scale, output and input markets are perfectly competitive, and factors are utilized at a constant rate. If any one of these assumptions is violated, this traditional measure of TFP may yield a biased estimate of technical change. The model

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1 Justice Department brought a major antitrust suit against AT&T in 1974. In 1982, this suit was settled by a consent decree that required AT&T to divest itself of all its local operating companies. AT&T completed the divestiture by 1984.

2 For a recent survey, see Good et al. (1997) and the references provided therein.

3 For an extended list of references on dynamic factor-demand models and their applications, see Nadiri and Prucha (1998). In addition, references in Good et al. (1997) provide extensive references on factor-demand models. For relevant studies pertaining to the telecommunications industry, see Bernstein (1989), Christensen et al. (1983), Denny et al.
considered here relaxes all of these assumptions to make the model more realistic.\(^4\) Within the context of this model, we define appropriate measures of technical change and decompose the traditional measure of productivity growth into the effect of technological change and other sources, such as scale and markup effects. We then further decompose the scale effect into specific components.

For the purpose of estimation, we specify a multioutput/multinput translog variable cost function. Furthermore, we assume that zero net investment implies that the marginal adjustment cost is zero in the long run (Bernstein & Nadiri, 1988). The variable cost function is given by

\[
\log(C'/w_m) = (B_0 + H dm + G wardm) + (B_1 + H dm) \log w_t \\
+ \sum_{i=2}^{i=2} (B_i + H dm) \log Y_{it} \\
+ \sum_{m=K,R} (B_m + H dm) \log K_{mt} \\
+ 0.5 (B_L \log w_t)^2 \\
+ \sum_{i=1}^{i=2} \sum_{j=1}^{j=1} B_{ij} \log Y_{it} \log Y_{jt} \\
+ \sum_{m=K,R} \sum_{n=K,R} B_{mn} (\log K_{mt} \log K_{nt}) + B_{TT} T_i^2 \]  

(1)

where the symmetry condition requires the parameters \(B_{ij} = B_{ji}\) for \(i, j = 1, 2\) and \(B_{nn} = B_{mm}\) for \(m, n = K, R\).

The definitions of the variables in equation (1) are as follows. The two variable factors are labor and materials, the two outputs are local service \((Y_1)\) and toll service \((Y_2)\), and the two quasi-fixed factors are physical capital stock \((K_0)\) and R&D capital stock \((K_0)\). The introduction of R&D stock as a separate quasi-fixed factor in the cost function from the physical capital allows us to test the hypothesis of static equilibrium of physical capital and R&D capital separately as well as jointly. This also permits us to estimate a quasi-fixed-factor-specific or asset-specific shadow price, which is a measure of the marginal value of Tobin’s \(q\). The asset-specific \(q\) value helps to explain investment behavior that differs across assets.\(^5\) In addition, this cost function allows us to identify separately the effect of traditional capital and the effect of R&D capital on the measured scale effect. The wage rate is normalized by the material’s price, i.e., \(w = w_t/w_m\), as is the variable cost, \(C'/w\). The normalization imposes the homogeneity restriction on the cost function. Intercept and slope dummy variables are used to capture the impact of divestiture on the cost structure of the industry. The dummy variables (dm) take value one for the period 1984–1987 and zero otherwise. Another dummy variable, “wardn,” is used to identify potential changes in the structure of the variable cost function during WWII.\(^6\) \(T_i\) is an index of time representing disembodied technical change. Subscript \(t\) is used to represent time.

The output demand functions are assumed to be log-linear and take the form:

\[
\log(Y_{it}) = \alpha_0 + \alpha_1 \log(P_{it}) + \alpha_2 \log(RGi) \\
+ \alpha_3 \log(TNi) + (1 - \alpha_2) \log(N) \tag{2}
\]

\[
\log(Y_{2t}) = \gamma_0 + \gamma_1 \log(P_{2t}) + \gamma_2 \log(RGi) \\
+ \gamma_3 \log(SVi) + \gamma_4 \log(TNi) \tag{3}
\]

where \(Y_{it}\) is the demand for service \(i (i = 1 (= \text{local}), 2 (= \text{toll}))\); \(P_{it}\) is the deflated price index for service \(i; TN_i\) is the number of existing telephone; \(N\) is the total population; \(SV_i\) is service-sector employment as a proportion of nonagricultural employment; and \(RG_i\) is the level of real GNP expressed in 1982 dollars. Equations (2) and (3) can be considered as a first-order approximation to arbitrary demand functions. We also assume that the preferences are such that the utility derived from the services in question is weakly separable from all the other goods and services in the individual’s utility function. Finally, we assume that the

\(^4\) For the theoretical analysis, see Nadiri and Nandi (1997). Our estimated structural model does not account for the A-J effect explicitly. The well-known A-J effect states that monopoly firms under a rate of return regulation tend to use more capital than the economically efficient level. We follow the reasoning of L. R. Christensen et al. (1983) who argue that firms will always attempt to minimize variable cost conditional on the level of capital. Therefore, even if it is agreed that the A-J effect is present, the variable cost model will be a valid specification. Furthermore, we also estimated the total cost function for this industry, and the scale estimates were quite similar to those obtained from the variable cost function. This similarity of scale estimates provides some evidence that any A-J effect that might exist for AT&T is not important enough to invalidate the estimates used in our TFP decomposition.


\(^6\) We also attempted to use separate dummy variables to capture the structural change in cost function due to introduction of competition in long-distance service. However, only the coefficient of the divestiture dummy appeared as statistically significant.

\(^7\) Thanks to Dr. Lester Taylor for his valuable suggestions regarding the form of demand functions of two outputs.
GNP deflator represents the aggregate price index of the other goods and services.

We adopted the forms of the demand functions used above after some experimentation with more-flexible forms.\(^8\) Due to the existence of externalities in the individual demand function, the number of persons who are connected with a telephone system has a positive effect on access and usage of telephone services. To capture this network externality effect, we include \(TN\) as an explanatory variable in the local and toll-service demand equations. The variable \(SV\) is included in the toll-service demand equation to capture the effect of the relative growth of the service sector, which tends to be a telecommunications-intensive sector of the economy. Population growth is considered as an important explanatory variable for the local-service demand equation, and GNP is considered as an important explanatory variable for both demand equations. These variables capture the effect of the growth of the aggregate income and population, as well as the effect of industry characteristics on the demand for the telecommunications services.

Applying Shepherd’s lemma to variable cost, we derive the share equations of variable inputs, using profit maximization conditions, we derive the revenue share equations. These two sets of equations characterize the equilibrium conditions for optimal choice of inputs and outputs.\(^9\) The factor share equations are given by

\[
S_{Li} = B_{Li} + H_{Li} dm_i + B_{LL} \log w_i + \sum_{i=1}^{i=2} B_{Lm} \log K_m + B_{LT} T_i
\]

where \(S_{Li} = w_i \nu_{ih} / C_y^i(t)\) is the share of labor in variable production cost. The share of materials can be derived as a residual, i.e., \(1 - S_{Li} = S_{Ri} = \nu_{im} / C_y^i(t)\).

The revenue share equations for local and long-distance services, given in terms of share in variable cost are as follows

\[
R_{Li} = [B_{Li} + H_{Li} dm_i + \sum_{j=1}^{j=2} B_{Lj} \log Y_j + B_{L1} \log w_i + \sum B_{Lm} \log K_m + B_{LT} T_i][1 + 1/\alpha_i]^{-1}
\]

\[
R_{Ti} = [B_{Ti} + H_{Ti} dm_i + \sum_{j=1}^{j=2} B_{Tj} \log Y_j + B_{T1} \log w_i + \sum B_{Tm} \log K_m + B_{TT} T_i][1 + 1/\gamma_i]^{-1}
\]

where \(\alpha_i\) is the price elasticity of demand for local service and \(\gamma_i\) is the price elasticity of demand for toll service.

Using the envelope theorem, we can derive the equilibrium conditions for the quasi-fixed factors. In equilibrium, the rental rate of any quasi-fixed factor is equal to the expected marginal benefit from that input and is measured by the magnitude of the decline in variable cost due to that factor. Equations (7) and (8) below characterize the equilibrium conditions for physical capital and R&D capital, respectively:

\[
-S_{Ri} = [B_{Ri} + H_{Ri} dm_i + B_{RR} \log K_{Ri} + B_{RT} T_i]
+ \sum_{i=1}^{i=2} B_{Rm} \log Y_m + B_{RT} \log K_{Ri} + B_{RT} T_i]
\]

\[
-S_{Ti} = [B_{Ti} + H_{Ti} dm_i + B_{RR} \log K_{Ri} + B_{RT} \log w_i]
+ \sum_{i=1}^{i=2} B_{Rm} \log Y_m + B_{RT} \log K_{Ri} + B_{RT} T_i].
\]

\(S_{R}\) represents the share of physical capital and \(S_{R} \) represents the share of R&D capital in variable cost in period \(t\).

The temporary or short-run equilibrium model is described by equations (1) to (6). The long-run equilibrium model is described by equations (1) to (8). The disturbances have a joint normal distribution. Furthermore, we allow for contemporaneous correlation across equations and allow for serial correlation in the residuals. Using the methodology developed by Schankerman and Nadiri (1986) for testing model specification, we test the null hypothesis of whether or not the fixed factors are at their long-run equilibrium levels.

III. Methodology of Measuring TFP Growth and Its Decomposition

The growth rate of TFP is traditionally defined as the difference between the rate of growth of output and the rate of growth of all inputs. We decompose the traditionally measured TFP growth into separate components and calculate them using the value of the parameter estimates of the structural model described in section II.

Following the methodology used in Nadiri and Prucha (1990), the conventionally measured TFP growth rate can be decomposed as

\[
TFP = -b/q + [\hat{Y}_r - \hat{Y}_c] + [1 + \rho^{-1}]\hat{Y}_c
\]

where

\[
q = 1 - \sum_{m=K,R} \eta_m;
\]

\[
\eta_m = \partial \log C^m / \partial \log K_m;
\]

\[
\eta_i = \partial \log C^m / \partial \log Y_i;
\]

\[
b = \partial \log C^m / \partial T;
\]

\[
\rho = (1 - \sum_{m=K,R} \eta_m) / \sum \eta_j \quad \text{for} \quad j = 1, 2
\]

\(^8\) Use of more-flexible forms of the demand function increases the number of parameters in the model, which then in turn reduces the degrees of freedom in estimation. To avoid that possibility, we use simple log-linear demand equations in our model.

\(^9\) See Diewert (1971), Bernstein (1989), and Fuss and Wawereman (1977) for the derivation of the share equations.
\( \hat{Y}_p \) and \( \hat{Y}_c \) are the measures of the weighted average of outputs \( Y_1 \) and \( Y_2 \), using the revenue shares and cost elasticity shares as weights, respectively. The three terms on the right side of equation (9) constitute the direct effect of technological change \(( -\beta \theta q )\), the effect of departure from marginal cost pricing \([ \hat{Y}_p - \hat{Y}_c ]\), and the scale effect \(([1 - \rho^{-1}] \hat{Y}_c)\).

The scale effect can be further decomposed into five components (see appendix A):

\[
\text{scale effect} = \sum_{i=1}^{5} \text{decomp}_i \quad i = 1, \ldots, 5. \tag{10}
\]

The expressions for the five different components are:

1) the exogenous-demand effect—

\[
\text{decomp}_1 = R_i \gamma D_1(\alpha_2 + B \eta_2 \alpha_1 \gamma_2) + D_2(\gamma_2 + A \eta_1 \gamma_1 \alpha_2)
\]
\[
+ N D_1(1 - \alpha_2) + D_2 A \eta_1 \gamma_1(1 - \alpha_2)
\]
\[
+ \delta V(D_2 \gamma_2) + T I N(D_1 \alpha_3 + D_2 \gamma_2)
\]

2) the factor-price effect—

\[
\text{decomp}_2 = \sum_{i=1}^{S} \hat{w}_i \{ D_1(\alpha_1(1 + \eta_2 B \gamma_1))
\]
\[
+ D_2 \gamma_1(1 + \eta_1 A \alpha_1)\}
\]

3) the quasixed factors effect

\[
\text{decomp}_3 = \sum_{m=K,R} \eta_m \hat{K}_m \{ D_1(\alpha_1(1 + B \eta_2 \gamma_1))
\]
\[
+ D_2 \gamma_1(1 + A \eta_1 \alpha_1)\}
\]

4) the impact of technology on scale (the indirect effect of technology)—

\[
\text{decomp}_4 = T \{ D_1 \alpha_1(1 - \eta_2 B \gamma_1) + D_2 \gamma_1(1 + \eta_1 A \alpha_1)\}
\]

5) the effect of changes in cost elasticity and markup—

\[
\text{decomp}_5 = (D_1 + D_2 A \gamma_1 \eta_1)(\alpha_1 \eta_1 + \alpha_1(1 + \theta_1))
\]
\[
+ (D_2 + D_1 B \alpha_1 \eta_2)(\gamma_1 \eta_2 + \gamma_1(1 + \theta_2))
\]

where

\[
D_1 = (1 + \rho^{-1})(\eta_2 \sum_{j=1,2} \eta_j)A \quad \text{where}
\]
\[A = 1/(1 - \alpha_1 \eta_1 - 1), \quad \text{and}
\]
\[
D_2 = (1 + \rho^{-1})(\eta_2 \sum_{j=1,2} \eta_j)B \quad \text{where}
\]
\[B = 1/(1 - \gamma_1 (\eta_2 - 1))
\]

The critical elasticities for our calculation are the price elasticities of demand, \( \alpha_1 \) and \( \gamma_1 \), the markup of prices over their marginal costs, \( \theta_1 \) and \( \theta_2 \); the elasticity of demand with respect to per capita income \( \alpha_2 \) and \( \gamma_2 \); and the output cost elasticities of the two outputs, \( \eta_1 \) and \( \eta_2 \). These elasticities can be obtained from the estimates of the structural model shown in table 1. \( S_i \) is the share of the \( i \)th input in variable cost. The rest of the variables are defined in section II. A dot above a variable refers to the growth rate of that particular variable.

The above analysis reveals the importance of the relationship between the price elasticity of demand for the two services and the scale effect. If the two demand functions are completely price inelastic (\( \alpha_1 = \gamma_1 = 0 \)), then changes in real factor prices or changes in quasixed factors have no effect on output. In this case, the third term (total scale effect) in equation (9) will only contain the effect of exogenous demand variables on the scale effect. In order to apply the decomposition methodology outlined here, we need the estimates of the demand and cost elasticities.

### IV. Estimation Results

We jointly estimate the demand and supply equations described in section II by using the time-series data of the U.S. telecommunications industry from 1935 to 1987 described in detail in appendix B. The model is nonlinear in its parameters and variables. Therefore, we employ a nonlinear, three-stage, least squares (N3SLS) method using a set of instrumental variables. We find first-order autocorrelation in the residuals of the system of equations and correct for this in the estimation procedure.

We estimate the model both with and without the restriction of long-run equilibrium condition for the two fixed factors of production, physical capital and R&D capital. Employing the procedure developed by Shanker and Nadiri (1986), we perform a general test of the joint hypothesis that both quasixed factors are at their long-run equilibrium levels. The test results support the short-run equilibrium specification of the model. Therefore, the derived elasticities and other results presented below are based on the parameter estimates of the short-run equilibrium model rather than the long-run model. The estimated parameters of the cost and demand equations based on the short-run model are presented in table 1. The model fits the data very well. The majority of the parameter estimates are statistically significant, and the estimated cost function satisfies the theoretical restrictions. We summarize the important characteristics of the demand and cost side of the industry below.\[10\]

\[10\] For a detailed analysis of the changing structure of the cost and demand side of the industry, see Nadiri and Nandi (1997).
A. Demand Elasticities

The demand elasticities are presented in Table 2a. The results show that, at the industry level, the demand for both local and toll service are price inelastic. However, the demand for local service is relatively more inelastic than that for toll service. These results are consistent with the results of several earlier studies (Taylor, 1980; Gatto et al., 1988, 1991). The results also suggest that the existing number of telephones is an important determinant of demand for both local and toll service. This result is due to the network externality effect on demand. The growth of GNP and the information intensity of the society (SV) play important roles in explaining the rapid growth in demand for toll service in the last two decades.

B. Cost Elasticities

Important cost elasticities are reported in Table 2b. The elasticities of variable cost with respect to increases in physical and R&D capital stock are shown in column 2 and 3 of Table 2b. Variable costs decline with increases in the levels of these quasi-fixed inputs. The cost elasticity of physical capital exceeds by several orders of magnitude that of R&D capital. This result partly reflects their relative cost shares.
However, both these elasticities increase over time, particularly since 1970s. This implies that utilization of both physical capital and R&D capital became more efficient when competition was introduced in the long-distance market. Oum and Zhang’s 1991 study supports this view.

The variable cost elasticities of local and toll services are shown in columns 4 and 5 of table 2b. The results indicate a very low variable cost elasticity for toll service and a relatively high cost elasticity for local service. On average, a 1% increase in output causes an increase of 0.18% in the variable cost for toll service and an increase of 0.89% in the variable cost for local service. In the post-1970 period, while the cost elasticities of local service increased continuously, those of toll service declined significantly. This decline is likely to be the result of the introduction of competition in the toll-service market introduced by the FCC, which in turn encouraged efficient utilization of all inputs and faster adoption of new technology. No such competition was present in the local service production under regulated monopoly, and, therefore, these results are conspicuously absent from this market. The observed trends became more prominent in the post-divestiture period. During this period, the local network access costs of long-distance carriers were reduced by a considerable amount causing a decline in the cost of providing toll service.

The overall scale elasticity effect is presented in the last column of table 2b, indicating that the U.S. telecommunications industry experienced increasing returns to scale during the sample period. The scale effect is low during the early years of the sample.

V. Total Factor Productivity Growth and Its Decomposition

The TFP growth and its decomposition are shown in table 3 and in figure 1. The TFP growth rate for each year is estimated using the formula given in section III. Theoretically, these estimated TFP growth rates should be equal to the values of conventionally measured TFP. The average annual TFP growth rates for various subperiods and for the entire sample period are shown in column 2 of table 3. The results indicate that the TFP growth in the U.S. telecommunications industry since 1938 has been positive and very impressive, particularly over the period 1965–1983. There was a substantial drop in the TFP growth rate from 1945–1954 due to the large increases in employment and capital investment in this period. TFP growth greatly declined since the divestiture. This is mainly due to a decline in the contribution of technological change and nonmarginal cost pricing. During the period 1975–1983, the growth rate of TFP was much higher than during the period before 1975. The substantial acceleration in TFP growth in 1975–1983 may be attributed partly to the increase in competition in the telecommunications industry. However, during the subperiod 1985–1987, the rate of productivity growth has diverged significantly from this pattern. Average annual TFP growth rate was 5.3% during the period 1975–1983, and declined substantially in the post-divestiture period to about 2.4%.11

To decompose TFP into its constituent components, we use the model parameters, the estimates of different elasticities described in section IV, and the formula described in section III. We discuss the changing behavior of these different components in the following sections A through C. These different components of TFP growth rates are shown in columns 3 through 11 of table 3.

A. The Direct and Indirect Effects of Technical Change

As shown in table 3, the direct impact of technological change is the major contributor to TFP. The contribution is about 50% to 60% until the middle of the 1970s. In absolute terms, it accounts for as much as 1.8% to 2.5% of TFP growth per annum between 1938 and 1974. Since 1974, the contribution of nonmarginal-cost pricing (markup) and the contribution of the growth of scale have gradually increased, while the contribution of technological change has declined considerably.

In addition to the direct impact of technological change, the indirect impact of technical change shown in column 10

11 Our estimated TFP growth is consistent with estimates made by Nadiri and Schankerman (1981). They use the predivestiture Bell System data which are comparable to our data. Other studies using longer time-series data show the same trend in TFP growth of the U.S. telecommunications industry as observed in the present study, albeit with slight differences in the absolute level. See the studies done by Crandall (1991) and Gort and Sung (1996). One possible reason for this discrepancy is the difference in the definition of the industry and the data used in each of these studies.
of Table 3 contributed on average about 0.2% of annual growth of TFP during the sample period. This indirect effect of technological progress is not often noted in most analyses of TFP growth. In general, due to the presence of other effects, the contribution of technical change will be overstated by nearly 50% (particularly since 1975), if the conventional measure of TFP growth rate is used as a measure of rate of technical change.

The rate of technical change grew in the early years of the sample. Between 1935 and 1974, it grew steadily, but, since 1974, the growth rate of technical change has increased very slowly. The rate has declined significantly in the postdivestiture period. We propose two possible reasons for this observation. The first is that the postdivestiture period is a transitional period for this industry. The second is that there are measurement problems that could be addressed with better and more recent data that account for quality changes of both inputs and inputs over time.

It is important to note, as shown in Figure 1, that the rate of technical change, when properly measured, is fairly stable and much lower than that of the conventionally measured TFP growth rate. The estimates shown in Table 3 suggest that conventional index TFP as a measure of rate of technical change is seriously biased upward. Using our more-precise measurements, we find that the estimated rate of technical change is approximately 50% smaller than the conventionally measured TFP.

![Figure 1](image)

**B. The Effect of Markup**

The contribution of markup, the result of nonmarginal cost pricing, is insignificant before the middle of the 1960s, but it increases subsequently. It represents over 50% of the measured TFP growth since 1975. The contribution of markup to TFP growth is shown in Figure 1. It fluctuates considerably over time and has the same movement as that of conventionally measured TFP growth rate.

It is interesting to investigate the sources of the changes in the markup for different services. Table 4 summarizes the actual price and the incremental costs for two outputs by subperiod. The results are shown in index form, setting $1970 = 1.0$. For local service, except for a few years in the beginning of the sample period, the actual price is always below its incremental cost. In contrast, the actual price for toll services is substantially above its incremental cost in every year. After 1970, the cost of local service starts to increase, and that of toll service starts to decrease rapidly. This pattern of price and incremental cost movement suggests that the price of local services increased in response to an increase in cost but less than proportionately, thus causing the estimated markup of local service to decline.

The decline in the actual price of toll service is less than proportional to the decline in its incremental cost. The main source of total markup shown in Figure 1 is due to the estimated markup in toll service, which increases substantially over the last several decades. This behavior indicates that marginal cost pricing is not the underlying pricing policy. The introduction of competition in toll services has reduced prices considerably since the mid-1970s. However, the more-rapid decline in the incremental cost of providing toll services has caused the overall markup on toll services to increase, particularly after the divestiture. This behavior of price and incremental cost in toll service encouraged more competitive entry and rapid adoption of the new technology to meet competitive pressure in this industry. This type of interaction of competition and technological advancement is

\[ ICC(Y) = (C/Y)^*(B_i + B_{12} \log Y_{23} + B_{12} \log Y_{24} + B_{12} \log w_{23} + B_{12} \log T_{23} + B_{12} \log T_{24} + B_{12} \log T_{25} + B_{12} \log T_{26}) \]  

\[ + B_{12} \log K_{23} + B_{12} \log K_{24} + B_{12} \log K_{25} + B_{12} \log K_{26} \]  

for \( i, j = 1, 2 \)
Table 4.—Actual Price and Incremental Cost (Index 1970 = 100) (1938–1987)

<table>
<thead>
<tr>
<th>Year</th>
<th>Incremental Cost of Local Service</th>
<th>Price of Local Service</th>
<th>Incremental Cost of Toll Service</th>
<th>Price of Toll Service</th>
</tr>
</thead>
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<tr>
<td>1944</td>
<td>0.3942</td>
<td>0.5065</td>
<td>0.1725</td>
<td>0.6061</td>
</tr>
<tr>
<td>1954</td>
<td>0.5221</td>
<td>0.7616</td>
<td>0.3091</td>
<td>0.9514</td>
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<tr>
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<td>0.5083</td>
<td>0.9497</td>
<td>0.2004</td>
<td>1.0537</td>
</tr>
<tr>
<td>1974</td>
<td>1.0281</td>
<td>1.2197</td>
<td>0.1835</td>
<td>1.1877</td>
</tr>
<tr>
<td>1979</td>
<td>1.6512</td>
<td>1.4823</td>
<td>0.1283</td>
<td>1.0811</td>
</tr>
<tr>
<td>1983</td>
<td>2.2288</td>
<td>2.0391</td>
<td>0.1044</td>
<td>1.3244</td>
</tr>
<tr>
<td>1987</td>
<td>3.1543</td>
<td>2.8790</td>
<td>0.0037</td>
<td>1.0506</td>
</tr>
</tbody>
</table>

a unique feature of the evolution of telecommunications industry in the U.S.

The above pattern of markup behavior may reflect several underlying phenomena. The behavior of the prices and incremental costs of local and toll services before and after the introduction of competition in long-distance services suggests that cross-subsidization existed between local and toll services in the predisturbance period. The absence of this cross-subsidization may cause the rapid increase in the price of local service in the postdivestiture period. The behavior of toll service is not influenced by the same factors, however. The incremental cost of toll service declined rapidly over time. Supply-side factors that may explain this behavior include overall technological progress in the communications and information industries within the US and abroad, rapid innovation and implementation of advanced technology in providing toll services due to competitive pressure, reduction in costs encouraged by competition, and reduction of access costs in the postdivestiture period. On the demand side, competition forced the toll price to decline continuously.

C. Scale Effects

The contribution of scale over the sample period and selected subperiods is shown in column 5 of table 3. The contribution of scale to total productivity growth is substantial; it accounts for approximately 26% of measured TFP for the period 1938–1944. The magnitude of the scale effect declines during the period 1945–1954, but rises subsequently until 1983, when it accounts for approximately 15% to 20% of TFP. In the postdivestiture period, the contribution from this source declines in absolute magnitude, but, as a percentage of TFP, it still accounts for around 25% of TFP growth.

As our formula in section III suggests, the scale effect can be further decomposed into several components. The magnitude of the contribution of each of these components is shown in table 3, columns 6 through 11. Changes in exogenous demand variables, such as aggregate income and population growth, account for most of the effect of scale on TFP. Changes in relative input prices and the interaction of technical change with scale of operation also contribute to the effect of scale to TFP. As depicted in figure 1 and table 3, the contribution of changes in aggregate demand to TFP growth varies over time. On average, changes in aggregate demand account for 20% to 30% of TFP growth. Figure 1 shows that the growth of exogenous demand has varied over the period particularly in the early part of the sample. Since 1950 (with some exceptions), it has been relatively stable and a growing source of TFP growth rate. In absolute value, the growth in aggregate demand due to movement of macroeconomic variables (total income and population) contributes to approximately 0.70% to 0.76% of TFP growth per year during the period 1965–1987. For the entire sample period, the average per-year contribution of exogenous demand factor to TFP growth is about 0.71%.

Even if we assume that the demand for two outputs are totally price inelastic, our estimates show that, on average, about 0.49% of TFP growth could be generated as a result of an increased demand due to changes in macro variables like population growth or growth of GNP, and/or due to a structural change like an increase in the information intensity of the economy. The importance of the macro variables for telecommunication services demand is also reflected in the estimated parameters reported in table 1.

As shown in column 7 of table 3 and in figure 1, the contribution of relative factor prices to TFP growth has been relatively small, mostly negative, but varying over different subperiods. Relative factor prices contribute to about −0.13% TFP growth per year during 1955–1964 and nearly 0% per year during 1975–1983. Since then, input prices contribute positively to TFP growth, accounting for about 0.13% of TFP growth per year. These results suggest that, in recent years, the changes in input prices in the U.S. telecommunications industry have been fairly favorable compared to relative input prices in other industries in the economy.

Adjustments of the quasi-fixed factors such as physical and R&D capital have played, as expected, a relatively small role as a source of productivity growth, which is shown in column 8 of table 3. The indirect effect of technical change on scale (which is shown in column 10 of table 3) has varied over time, contributing about 0.20% to TFP growth between 1955 and 1983. In the postdivestiture period, it has contributed much less.

Our results show that the postdivestiture behavior of productivity growth is very different from the immediate predisturbance period. The following section summarizes the effect of 1984 divestiture on the cost structure of the industry and on its productivity growth.

VI. The Effect of Divestiture

To study the impact of the 1984 divestiture on the cost of production, we include dummy variables with a value of one for the period 1984–1987 and zero for the remaining years in the sample period. The dummy variables capture the shift in the cost function. The resulting changes in the demand for inputs and associated parameter estimates (H variables) are shown in table 1.
The overall impact of divestiture based on our parameter estimates is a reduction of about 2.63% of variable cost. Divestiture greatly influenced the demand for labor in the telecommunications industry. During 1984–1987, actual employment declined by 10.8%, whereas aggregate output grew on average by 6.5% per year. Labor productivity therefore increased significantly during the period after divestiture. Our estimates suggest that, out of the 10.8% decline in employment, the divestiture effect can explain almost 8.6%. This result is very similar to those reported by Crandall (1991) and Oum and Zhang (1991). The divestiture affected the cost of production of local and toll services in different ways. The coefficients of the dummy variables in table 1 show that divestiture caused the cost of toll service to decrease by about 2.8% and the cost of local service to increase by 23.7%. This suggests that the divestiture substantially changed the structure of cost in favor of toll service.

Despite an overall efficiency gain in production during the postdivestiture period, the U.S. telecommunications industry experienced a substantial decline in TFP growth during 1984–1987 from the productivity growth of previous decade. The TFP growth declined from an average annual growth of 5.35% during 1975–1983 to 2.40% in the postdivestiture period, a decline of approximately 55%. The changing composition of TFP growth (presented in table 3) offers a possible explanation of this phenomenon. During the postdivestiture period, the contribution of technology and markup towards TFP growth declined significantly from the previous period causing the reduction in TFP growth. The contribution of technology declined by 78% and that of markup declined by 40% from the previous period.13

However, we need to pose a caveat to these conclusions. Since the time-series data we used have very short postdivestiture period, further study using the extended postdivestiture is required. Recent FCC data provide a longer postdivestiture period, but, unfortunately, the data is structured differently from the previously reported time-series data for the industry. Therefore, proper adjustment is required to obtain time-series data with sufficient pre- and postdivestiture data.

VII. Concluding Remarks

This paper provides an integrated framework for studying the dynamic interaction between the demand and supply factors in influencing the U.S. telecommunications industry's productivity growth under different economic conditions and policy regimes. The main observation of this study is that conventionally measured TFP growth rate does not accurately measure the rate of technical change for a multiproduct firm when the pricing policy of the firm departs from marginal cost pricing and when economies of scale are present. The empirical results of this study reveal that a significant portion of the conventionally measured TFP growth rate can be attributed to the markup effect generated from nonmarginal cost pricing behavior, which has no implications for efficiency of production.

It is clear from our decomposition that the rate of technical change is a critical determinant of productivity growth in this industry. It accounts for approximately 50% of TFP growth during the entire 1935–1987 period. Furthermore, it tends to dominate during most of the subperiods. However, its effect begins to decline in the early 1980s, and declines substantially since the divestiture of the Bell System.

We decompose the scale effect into five components and establish the relationship between macroeconomic conditions, market size, and productivity growth, within the context of the U.S. telecommunications industry. The decomposition of scale effect establishes that input price inflation has not been a major source of decline in productivity growth in the industry. In fact, in the postdivestiture period, the growth rates of input prices have been less than the growth rate of general prices. This attribute contributes positively to the growth of TFP.

Finally, our study shows that the 1984 divestiture changed the structure of cost and the efficiency of production in the U.S. telecommunications industry in several ways. Labor productivity increased significantly in the postdivestiture period. Divestiture also caused the cost elasticity of toll service to decline significantly, while the cost elasticity of local service increased. This evidence suggests that a vertically integrated production process under regulated competition might encourage growth that is more balanced in production efficiency. Although the parameter estimates support the view that divestiture has increased overall efficiency, TFP growth declined significantly during this period due to the declining contribution of technological change. The explanation of this phenomenon is beyond the scope of this paper. Any observation of our study regarding the postdivestiture period requires further validation by future studies using time-series data with longer periods after 1984.

REFERENCES


13 A detailed explanation of this behavior is discussed in section V.
APPENDIX A

The Decomposition of the Scale Effect

\[
\text{Scale effect} = [1 - \rho^{-1}] \bar{Y}_C = [1 - \rho^{-1}] \left( \sum_j \eta_j \bar{Y}_j \right) \left( \sum_i \xi_i \right)
\]

(A.1)

Assume that prices of outputs are related to variable marginal cost according to the relation

\[
P_j = (1 + \theta_j) C_j \quad \text{or} \quad \bar{P}_j = P_j + \eta_j
\]

where \(P_j\) is the price of the \(j\)-th output, and \(\theta_j\) is the markup of the price of output \(j\) over its marginal cost. Differentiating equation (A.2) we get

\[
\bar{P}_j = (1 + \theta_j) + \bar{\eta}_j + \bar{C}_j - \bar{Y}_j \quad j = 1, 2.
\]

(A.3)

Taking total derivatives of our log-normal demand functions, we obtain

\[
\bar{Y}_1 = \alpha_1 \bar{P}_1 + \alpha_2 \bar{R}_G + \alpha_3 TN + (1 - \alpha_2) N
\]

(A.4)

\[
\bar{Y}_2 = \gamma_1 \bar{P}_2 + \gamma_2 \bar{R}_G + \gamma_3 SV + \gamma_4 TN
\]

(A.5)

Substituting \(\bar{P}_1\) and \(\bar{P}_2\) from equation (A.3) into (A.4) and (A.5) we can solve for \(\bar{Y}_1\) and \(\bar{Y}_2\). By then substituting these expressions in equation (A.1) and manipulating them, we derive the decomposition of the scale effect that is described in section III.

APPENDIX B

Data Sources

The primary source of the data used in this analysis is the telephone industry data published by the Federal Communications Commission (FCC) in the annual reports (1950-1988), entitled Statistics of Communications Common Carriers. This source provides information about all local and long-distance companies that report to the FCC. Since many long-distance carriers (such as MCI and Sprint) do not report to the FCC at the same level of detail as does AT&T, the FCC industry data excludes these carriers. No detailed data about these carriers were available from any other source. Hence, the data used in our estimates include only AT&T, Alascom, and all reporting local carriers. Despite this omission, we believe that the major characteristics of the industry are captured by our data because, up until recently, these non-AT&T carriers constituted only 10% to 15% of the long-distance market. Data for a few variables were missing during the years 1984-1987. We compensated the missing data by using information available in various FCC reports, in the USS Industrial Outlook (1991), and in reports published by the United States Telecommunication Association (USTA), 1980-1988, and by the U.S. Bureau of Labor Statistics (1992).

The data for local and toll services were obtained from the FCC annual reports. The total local output and total toll output are measured by the number of calls (referred to as "messages") in each category. The missing observations for toll messages were generated based on the information about average revenue per toll message and total toll revenue in the corresponding years. Output price indices for the period 1935-1971 were computed from the FCC's data on average revenue per call for local and toll services. We then extended these indices to 1987 by using information about disaggregated prices indices obtained from the 1987 issue of the annual FCC report.

The labor input in the industry was constructed from the industry employment series recorded in the FCC reports. The labor input in this study is an estimate of the man-hours worked by the labor force. Missing employment figures for 1982-1983 were obtained by combining information about total compensation of each year and the corresponding average annual compensation in this industry. For 1984-1987, we had no such information. Therefore, based on information from the U.S. Bureau of Labor Statistics and the 1991 issue of the USS Industrial Outlook, we estimated industry employment for 1984-1987 to make it consistent with
our pre-1984 data. Once we constructed the missing employment figures, we computed the missing values of total wage compensation for employees by combining the information about the number of employees with the information about average compensation per employee per annum. We derived the nominal wage rate per hour by combining the FCC statistics of wage compensation per employee per annum and information about average weekly hours in telecommunications services, using the assumption of fifty weeks of work in a year. Jorgenson, Gollop, and Fraumeni (1987) report statistics on average weekly hours for the period of 1948–1979. We extended this data backward and forward by using the behavior of average weekly hours per person for the manufacturing sector available in The Economic Report of the President (1988).

We obtained our data series for material inputs by deflating the cost of material inputs (derived from FCC reports) by the material price index obtained from The Economic Report of the President. The stock of physical capital was constructed from the investment series by using the perceptual inventory method and by using a 4.01% depreciation rate. We obtained the investment series from the book values of gross stock of capital published in the FCC reports. We then deflated this series by the equipment price deflator of the manufacturing sector obtained from The Statistical Abstract (1987–90). Data on the real stock of R&D capital was constructed by a similar method, using AT&T's R&D expenditures as a proxy for total telecommunications industry R&D expenditures, and deflating them with an appropriate price index. The depreciation rate for the R&D stock is assumed to be 10% per annum. The R&D investment series is lagged by four periods to reflect the gestation period between R&D expenditure and its impact on the stock of R&D capital.

The service price or user cost of capital for each type of capital was constructed by applying a formula similar to one used by Nadiri and Mamaneeas (1994). We used this along with data on implicit price index, the depreciation rate appropriate for each type of capital as mentioned above, the nominal rate of return on capital measured by the average interest rate on Tripler-A bond, and the data on tax parameters such as the corporate income tax and investment tax credit. All price deflators used in the construction of variables of the model have been normalized to be equal to one in 1982.

We separated the labor, capital, and material inputs that are used directly in R&D activities. The National Science Foundation provides a breakdown of R&D expenditure by type of cost such as labor cost, materials, and research equipment costs. We used these cost-allocation weights as proxies to distribute the cost of R&D activities in the U.S. telecommunications industry. To avoid double-counting, we deducted the amount of labor, materials, and capital used in R&D activities from their aggregate measures. The production costs were also adjusted for intra-industry receipts and payments for access charges in the post divestiture period.

Values of macroeconomic variables such as GNP, population, service-sector employment, etc. were obtained from the Economic Report of the President (1988) and the Historical Statistics of the U.S.: Colonial Times to 1970. Time-series data on the number of existing telephones were obtained from the various FCC annual reports. A time trend was used as a proxy for disembodied technological change.

Some adjustments were made to the original data to make the postdivestiture data consistent with the predivestiture industry data. Both series required adjustment on operating cost and on operating revenue for the years 1984–1987, because of the court-ordered divestiture. Figures for operating cost and operating revenue for the period 1984–1987 were adjusted by subtracting access charges (paid to local companies by long-distance companies for the use of local company facilities at each end of the long-distance call) for each year. Figures for access charges for the aforementioned four years were obtained from the FCC annual report of 1988. This adjustment was made to avoid double-counting of access charges. Also, we did not include miscellaneous revenue in our analysis. Therefore, we adjusted the cost figures downward to eliminate the components of cost associated with miscellaneous revenue.

The analysis of the time-series data used in this study shows that the U.S. telecommunications industry has experienced substantial changes in the output mix, toll and local prices, and quantities and prices of inputs over the sample period. These changes are reflected in the growth rates of total cost and cost shares of the inputs. All these changes have contributed to the growth rate of productivity and have responded to the changes in technical progress in this industry. The estimated model is designed to delineate the contributions of different factors to the productivity growth.

See Nadiri and Nandi (1997) for further details.