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

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Abstract

This paper examines the sources of productivity growth of the U.S. telecommunications industry over an extended period, from 1935 to 1987. A structural model is formulated that takes account of both the changes in cost and the demand side of the industry. The decomposition of the TFP growth presented in this study delineates the contribution of aggregate demand, information intensity of the economy, relative factor prices, the direct and the indirect effects of technological progress and R&D investment. The influence of changing output mix on the cost structure and the adjustment costs of changing quasi-fixed inputs like physical capital and R&D capital are discussed. Further, the impact of price-cost margin and the regulatory actions such as the 1984 diversity of the Bell System on employment and productivity growth are analyzed. The evolution of mark-up behavior (i.e., price-cost margin) for toll and local services is studied by examining the movement of price and incremental cost over time.

Keywords: Productivity, Telecommunications, Rates of Return

JEL Classification Numbers: O4, O32, L5, L7

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INTRODUCTION

In this paper we examine the productivity performance of the U.S. telecommunications industry over the extended period of 1935-1987. To delineate the forces that shape the course of the productivity growth over this time span we estimate a structural model that captures the dynamic interactions between the structure of production and the output demand. The model identifies the contributions of forces on both the supply and the demand sides of the industry which affects its productivity growth. Previous literature on the subject has emphasized the supply side factors as the primary determinants of productivity growth. We believe, however, that such an analysis is incomplete and a more complete analysis of productivity growth requires consideration of the influence of the demand factors as well. In this undertaking, we link the macroeconomic conditions that affect the industry demand with models of interrelated demand for factors of production or cost of adjustment models. The most interesting observation of this study is the interplay between the technological progress and the market condition and its dynamic impact on the demand and cost sides of the industry.

To integrate the diverse factors from both the demand and supply sides, we formulate a multi-output and multi-input model that is estimated using the annual data for the period mentioned. Our analysis adopts a decompositional approach in order to identify the different sources of productivity growth and to study their changing contributions over time. More specifically our analysis identifies:

i) the role played by changes in aggregate economic variables such as aggregate income, population growth, and the growth of information intensity of different sectors;
ii) the effect of movement of relative input prices;
iii) the direct and indirect impacts of autonomous technological advancement;
iv) the impact of market characteristics, such as price-cost margin, and of regulatory activities, such as the 1984 divestiture of the Bell System.

Both the theoretical formulation and empirical results show that the growth in macroeconomic variables causes an exogenous shift in demand for telephone services which in turn allows the industry to enjoy the higher productivity growth in the presence of increasing returns to scale. This occurs due to the interplay of the growth of demand and the scale economies of production. The basic conclusion is that the size of the market is of crucial importance for increasing efficiency of production in this industry. The impact of the extent of the market on TFP growth arises from the interplay of scale of operation and technological change. Ignoring its role may lead to sub-optimal production decisions and incorrect measurements of the contribution of technological change.

By establishing the relationship among exogenous macroeconomic variables, the level of demand and the efficiency of production, the present analysis allows us to study the links among macro economic condition, market size and efficiency of production, especially in the context of the US telephone industry. Our empirical results reveal that a significant portion of the traditionally measured TFP growth can be attributed to non-margin cost pricing behavior. This suggests that the often used conventional index of productivity change, i.e., total factor productivity growth (TFP), incorrectly measures the true shift in production function associated with technical change in the presence of non-marginal cost pricing policy.

Lastly, the behavior of the markup (the price-cost margin) of the toll service indicates the interesting relationship between competition and technological progress. It appears that the combined effect of these two elements has accelerated the degree of competition and technological growth in this industry. Growing competition in the last few years has led to rapid technological innovation which in turn has brought more competition and more technological innovation.

The paper is organized into five sections. Section 1 briefly explains the theoretical foundations and empirical implementation of our model. In section 2 we describe the methodology for the decomposition of total factor productivity growth. In section 3 we describe the data sources and present a summary of the primary results obtained from the model estimation, that is, the important demand and cost elasticity estimates. In section 4 we discuss the empirical results of partial and total factor productivity growth and analyze the different sources of TFP growth over time. In section 5 we provide a summary of the results.

1. THEORETICAL MODEL AND EMPIRICAL IMPLEMENTATION

In the past, extensive research has been done to define, measure, and analyze the growth of total factor productivity (TFP) using aggregate level, industry level and firm level data for the US and other countries.[1] The traditional measure of total factor productivity based on the Divisia index formula assumes, in particular that: (1) producers are in long-run equilibrium, (2) the technology exhibits constant returns to scale, (3) output and input markets are perfectly competitive, and (4) factors are utilized at a constant rate. If any one of those assumptions are violated, the traditional measure of total factor productivity will in general yield biased estimates of technical change. The puzzle of the observed slowdown of productivity growth during the 1970's has initiated a critical methodological review of the traditional measures of productivity.[2]

The model considered here relaxes all of the above listed assumptions that correspond to the traditional measure of productivity. In the following we define, within the context of our model, appropriate measures of technical change. Furthermore we decompose the traditional measure of productivity into technical change and sources of potential bias.

In our analysis we use a multi-output multi-input model similar to the one used by Bernstein (1989) and the one used by Nadiri and Bernstein (1990). The production technology of the telecommunications industry is given by

$$T\,[\,Y(t), V(t), Z(t), I(t), T(t)] = 0 \tag{1}$$

where Y(t) is the vector of outputs, V(t) is the vector of variable inputs, Z(t) is the vector of quasi-fixed inputs (capital and R&D), I(t) is the vector of additions to the quasi-fixed inputs and T(t) is an indicator of technological progress in time t.

The physical capital accumulation is assumed to take place by the following relation:

(2) $$K(t) = I_K(t) + (1-\delta_k)\, K(t-1)$$

where K(t) and $I_K(t)$ represent the stock of capital and investment in period t respectively and δ_k is the fixed depreciation rate on the capital.

The R&D capital accumulation is assumed to take place by the following relation:

(3) $$R(t) = I_R(t-4) + (1-\delta_r)R(t-1)$$

where R(t) and $I_R(t-4)$ represent the stock of R&D capital and investment in R&D in period t-4 and δ_r is the fixed depreciation rate on the R&D stock. Investment in R&D is lagged four years to account for the gestation period.

The demand side of the industry can be represented by the demand functions

(4) $$X_{it} = D_i(P_{it}, A_{it})$$

where i=1,2 and X_{it} is the demand for product i, P_{it} is the price of product i, and A_{it} is the vector of explanatory variables in the demand equations.

The objective of the producer is to maximize the expected present value of the flow of funds. Assuming $X_{it}=Y_{it}$, the objective function of the producer can be described as:

(5) $$H(t) = \sum_{s=1}^{\infty} E(t)\mu(t,s)\sum_{i=1}^{2}[D(P_{it}, A_{it})P_{it} - C_p^v(s) - P_{IK}(s)I_k(s) - P_{IR}(s)I_r(s)]$$

where P_{IK} and P_{IR} are the acquisition prices of the quasi-fixed factors of capital and R&D stock, C_p^v is the variable production cost, $\mu(t,s)$ is the discount factor, E is the conditional expectation (conditional on current information), and I(t) is an m-dimensional vector of net investments of quasi-fixed factors. The producer determines its demand for inputs and prices of its products so that the expected present value of the flow of funds given by equation (5) is maximized subject to the constraints given by (1) - (4).

The producer's decision regarding demand for inputs can be solved in two steps. The producer first determines the demands for the variable inputs in such a way as to arrive at the minimum point on the short run variable cost function. Since the US telecommunications industry was under rate of return regulation during most of our study period, we should mention one important point regarding our assumptions. We assume that firms pursued variable cost minimization behavior without regard to the possibility of Averch-Johnson types of distortions. The minimized variable cost function then depends on variable factor prices, output quantities, quasi-fixed factors, gross investment levels and the rate of technological change. It can be written as

(6) $$C_p^v(t) = F[W(t), Y(t), Z(t), I(t), T(t)]$$

where W(t) is the vector of factor prices and other arguments are as defined before.

By applying Shepherd's Lemma to the variable cost function we obtain the variable factor demand functions as

(7a) $$V_j(t) = F_{wj}[\, W(t), Y(t), Z(t), I(t), T(t)]$$

where the subscript wj denotes partial differentiation of the variable cost function with respect to the price of factor j.

The product market equilibrium conditions are determined from variable cost function along with profit maximizing conditions as

(7b) $$S_{yi}(t)\,(1+1/e_i) = F_{yi}\,[W(t), Y(t), Z(t), I(t)]\,(Y_{it}/C^{vp}(t)$$

where $S_{Yi}(t) = P_{it}Y_{it} / C_p^v(t)$ is the ith output revenue to cost ratio for i=1,2. $F_{Yi}(\bullet)$ is the partial derivative with respect to output Y_i and e_i is the own price elasticity of demand for output i. It implies that at product market equilibrium, revenue cost ratios are proportional to cost flexibility. Equations (6), (7a) and (7b) together define the short run equilibrium condition.

Then by substituting the variable cost expression into equation (5), the demand for each fixed factor is determined by minimizing the present value of the cost of production and maximizing the value of H(t). Assuming that in the long run equilibrium, $\Delta Z(t) = 0$, and applying the envelope conditions, we can implicitly define the long run equilibrium levels of demand for the fixed factors as

$$(8) \qquad -F_{zi}\,[W(t), Y(t), Z(t), I(t), T(t)] = r_i \qquad \text{for } i= K, R$$

where the shadow price and the opportunity cost of funds are equal. The left hand side of (8) denotes the marginal reduction of variable cost due to fixed factor Z_i or can be defined as the shadow price of factor Z_i while r_i in the right hand side of (8) represents the opportunity cost of the fixed factors Z_i. The divergence between the shadow price and the opportunity cost of funds reflects the divergence between the observed and long run equilibrium levels of fixed factors. Equations (6), (7a), (7b) and (8) define the long run equilibrium condition.

For the purpose of estimation, we must choose a specific functional form for the variable cost function and specific functional forms for the two demand functions. We specify the variable cost function in a translog form and assume that the marginal adjustment cost is zero in the long run (Bernstein and Nadiri, 1988) when net investment is zero. The variable cost function is given by

$$\log(C_p^v / p_m)_t = (B_0 + H\,dm + Gwardm) + (B_L + H_L dm)\log w_t + \sum_{i=1}^{i=2}(B_i + H_i dm)\log Y_{it}$$

$$+ \sum_{m=K,R}(B_m + H_m dm)\log K_{mt} + 0.5[B_{LL}(\log w_t)^2 + \sum_{i=1}^{i=2}\sum_{j=1}^{j=2} B_{ij}\log Y_{it}\log Y_{jt}$$

(9) $$+ \sum_m\sum_n B_{mn}(\log K_{mt}\log K_{nt}) + B_{TT}T_t^2] + \sum_{i=1}^{i=2} B_{Li}\log w_t \log Y_{it}$$

$$+ \sum_{m=K,R} B_{Lm}\log w_t \log K_{mt} + B_{LT}\log w_t T_t + \sum_{i=1}^{i=2}\sum_{m=K,R} B_{mi}\log Y_{it}\log K_{mt}$$

$$+ \sum_{i=1}^{i=2} B_{iT}\log Y_{it}T_t + \sum_{m=K,R} \mathrm{B}_{\mathrm{mT}}\log K_{mt}T_t$$

where $B_{ij}=B_{ji}$ for i,j=1,2 and $B_{mn}=B_{nm}$ for m,n=K,R. The two variable factors are labor and material, the two outputs are local service (Y_1) and toll service (Y_2) and the two quasi-fixed factors are physical capital stock (K_K) and R&D capital stock (K_R). The wage rate is normalized by the materials price i.e., $w= w_L/w_m$ and variable cost is also normalized by the price of materials. The normalization imposes the homogeneity restriction on the cost function. Dummy variables (dm) are used to capture the impact of divestiture on the intercept and slope of the variable cost function. The dummy variables take value one for the period 1984-87 and zero otherwise. We also introduced another dummy variable "wardm" to identify potential changes in the structure of variable cost function during the WWII. T is an index of time representing disembodied technical change. Subscript "t" is used to represents time.

The output demand functions are assumed to be a log linear and take the form[3]:

(10) $\log(Y_{1t})= \alpha_0+ \alpha_1 \log(P_{1t}) + \alpha_2 \log(RG_t)+ \alpha_3 \log(TN_t)+ (1- \alpha_2) \log(N_t)$

(11) $\log(Y_{2t})= \gamma_0+ \gamma_1 \log(P_{2t})+ \gamma_2 \log(RG_t)+ \gamma_3 \log(SV_t)+ \gamma_4 \log(TN_t)$

where

Y_{it} : Demand for service i for i = 1 (=local) ,2 (=toll)

P_{it} : Deflated price of service i for i = 1 (=local) ,2 (=toll)

TN_t: is the number of existing telephone

N_t : Population

SV_t: service sector employment as a proportion of non-agricultural employment

RG_t: Real GNP expressed in 1982 dollars

The reasons for including SV in the toll service demand equation and TN in the local and toll services demand equations are explained in more detail in the subsequent discussion. Population growth is considered an important explanatory variable for the local service demand equation, whereas GNP is considered an important explanatory variable for both demand equations. They capture the effect of the growth of the aggregate income and population as well as the industry characteristics on the demand for the telecommunications services.

Applying Shepherd's Lemma to the variable cost function (Diewert, 1974, Bernstein, 1989) we derive the factor share equation (share in variable cost), and applying the profit maximization condition we derive the revenue share equations (Fuss and Waverman, 1978). The factor share equations characterize the equilibrium conditions for the variable factors of production, and the revenue share equations represent the equilibrium conditions of the output markets.

The factor share equations are given by:

$$(12) \qquad S_{Lt} = B_L + H_L dm_t + B_{LL}\log w_t + \sum_{i=1}^{i=2} B_{Li}\log Y_{it} + \sum_{m=K,R} B_{Lm}\log K_{mt} + B_{LT}T_t$$

where $S_{Lt} = w_{Lt}v_{Lt} / C_p^v(t)$ is the share of labor in variable production cost. The share of materials can be derived as a residual i.e., $1 - S_{Lt} = S_{Mt} = w_{mt}v_{mt} / C_p^v(t)$.

Revenue share equations(share in variable cost) for the two products are given by:

$$(13)\quad R_{1t}=[B_1+H_1dm_t+\sum_{j=1}^{j=2}B_{1j}\log Y_{jt}+B_{L1}\log w_t+\sum B_{1m}\log K_{mt}+B_{1T}T_t]\,[1+1/\alpha_1]^{-1}$$

$$(14)\quad R_{2t}=[B_2+H_2dm+\sum_{j=1}^{j=2}B_{2j}\log Y_{jt}+B_{L2}\log w_t+\sum B_{2m}\log K_{mt}+B_{2T}T_t][1+1/\gamma_1]^{-1}$$

where α_1 is the price elasticity of demand for local service and γ_1 is the price elasticity of demand for toll service.

Using the envelope condition, 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. In other words, the rental rate is equal to the magnitude of the decline in variable cost due to that factor. Equations (15) and (16) below characterize the equilibrium conditions for physical capital and R&D capital respectively.

$$(15)\quad \begin{aligned} S_{Kt}=&-B_K-H_Kdm-B_{KK}\log K_{Kt-1}-B_{LK}\log w_t-\sum_{i=1}^{i=2}B_{iK}\log Y_{it}\\ &-B_{KR}\log K_{Rt}-B_{KT}T_t\end{aligned}$$

$$(16)\quad \begin{aligned} S_{Rt}=&-B_R-H_Rdm-B_{RR}\log K_{Rt-1}-B_{LR}\log w_t-\sum_{i=1}^{i=2}B_{iR}\log Y_{it}\\ &-B_{KR}\log K_{Kt}-B_{RT}T_t\end{aligned}$$

where S_K represents the share of capital expenditure in variable cost and S_R represents the share of R&D expenditure in variable cost in period t.

The temporary or short run equilibrium model is described by equations (9) to (14). Since adjustment cost is zero in the long run, the long run equilibrium situation is described by the system of equations (9) to (16). For estimation purposes, we add an additional disturbance terms to share equations, cost equation and demand equations. The disturbances are specified to have a joint normal distribution but contemporaneous correlation across the equation is allowed and allowance is made for serial correlation in the residuals. Using the methodology developed by Shankerman and Nadiri(1986) for testing model specification, we test the null hypothesis that whether the fixed factors are at their long run equilibrium levels.[4]

Once we estimate the model, then using model parameters, we calculate the total factor productivity growth and its different components. The parameter estimates for cost and demand equations are presented in tables 2a and 2b.

2. METHODOLOGY OF MEASURING TFP GROWTH AND ITS DECOMPOSITION

The growth of total factor productivity (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 various components using the value of parameter estimates obtained from the econometric estimation of the structural model described in Section 1.

We first decompose the measured total factor productivity (TFP) growth into three parts--contributions of non-marginal-cost pricing, technological change, and scale economies. Then we further decompose the scale economies into five parts to identify different sources which contribute to measured scale economies. The main forces which affect scale economies are changes in technology, exogenous growth in demand and changes in real prices of factor inputs. If economies of scale exist, average cost declines with the increase in the level of output. Since technological change increases output for a given level of input, and thus changes the derived demands for inputs, the presence of increasing returns to scale and the induced growth of output raises TFP growth. This can be defined as the indirect contribution of technical change to TFP growth. A further source of TFP growth is the adjustment of fixed factors which is also accounted for in our analytical and econometric framework.[5]

Assuming that the producer minimizes the cost of production, the total cost function can be defined as

$$(17)\qquad \begin{aligned} C(t) &= C_p^v(t) + \sum_{m=K,R} w_{mt} K_{mt} \\ &= g[Y(t), W(t), W_m(t), T(t)] \end{aligned}$$

where C is the total cost of production, Y(t) is the output vector, W(t) is the vector of input prices, $W_m(t)$ is the vector of prices of quasi-fixed factors and T(t) is the technological indicator. To simplify the notation, we will drop the "t" subscript in our subsequent analysis.

Following the approach used by Denny, Fuss and Waverman (1981), we can link the shift in the cost function due to technical change to the measurement of TFP growth and can decompose TFP growth into the following three components:

$$(18)\qquad \begin{aligned} T\dot{F}P &= \dot{Y} - \dot{F} \\ &= -\dot{B} + (1 - \sum \eta_j^T)\dot{Y}_c + (\dot{Y}_p - \dot{Y}_c) \end{aligned}$$

where $(\bullet)$ denotes growth rate

$$\dot{B} = \partial \log C / \partial T$$

$$\eta_j^T = \partial \log C / \partial \log Y_j \qquad \text{for } j = 1,2$$

$$\dot{Y}_P = \sum_j (P_j Y_j / R) \dot{Y}_j$$

$$\dot{Y}_C = (\sum_j \eta_j^T)^{-1} (\sum_j \eta_j^T \dot{Y}_j]$$

$\dot{B}$ denotes the shift in the production function due to technical change; $(1 - \sum \eta_j^T) Y_c$ represent the effect of scale; $(\dot{Y}_P - \dot{Y}_C)$ measures the divergence between revenue shares and cost share weighted growth rates of output.

Following Nadiri-Prucha (1990b), it can be shown that

$$\eta_j^{T} = \partial \log C / \partial \log Y_j$$

(19) $$= (\partial \log C_p^{v} / \partial \log Y_j) / q = \eta_j / q$$

$$\dot{B} = (\partial \log C_p^{v} / \partial T) / q = \dot{b} / q$$

where $q = 1 - \sum_{m=K,R} \eta_m$

$$\eta_m = \partial \log C_p^{v} / \partial \log K_m$$

$$\eta_j = \partial \log C_p^{v} / \partial \log Y_j$$

$$\dot{b} = \partial \log C_p^{v} / \partial T$$

Substituting (19) in (18) we have

(20) $$T\dot{F}P = -\dot{b}/q + [1 - \sum_j \eta_j / (1 - \sum_m \eta_m)]\dot{Y}_c + [\dot{Y}_P - \dot{Y}_C]$$

$$= -\dot{b}/q + [1 + \rho^{-1}]\dot{Y}_C + [\dot{Y}_P - \dot{Y}_C]$$

where,

$$\rho = (1 - \sum_{m=K,R} \eta_m) / \sum_j \eta_j$$

The three terms in the right hand side of (20) constitute our decomposition of TFP growth. These components are:

(a) Direct effect of technological change $= -\dot{b}/q$

(b) Scale effect $= [1 - \rho^{-1}]\dot{Y}_c$

(c) Effect of departure from marginal cost pricing $= [\dot{Y}_P - \dot{Y}_C]$

The scale effect represented by the second term in equation (20) can be further decomposed:

(21) *Scale effect* $= [1 - \rho^{-1}]\dot{Y}_C$

$$=[1-\rho^{-1}](\sum_j \eta_j)^{-1}[\sum_j \eta_j \dot{Y}_j]$$

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

(22) $$P_j = (1+\theta_j)\partial C_p^v / \partial Y_j = (1+\theta_j)\eta_j C^{v_p} / Y_j$$

where P_j is the price of the jth output, θ_j is the markup of the price of output j over its marginal cost. Differentiating (22) we get

(23) $$\dot{P}_j = (1+\dot{\theta}_j)+\dot{\eta}_j+\dot{C}^v_p-\dot{Y}_j \qquad j = 1,2$$

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

(24) $$\dot{Y}_1 = \alpha_1 \dot{P}_1+\alpha_2 \dot{RG}+\alpha_3 \dot{TN}+(1-\alpha_2)\dot{N}$$

(25) $$\dot{Y}_2 = \gamma_1 \dot{P}_2+\gamma_2 \dot{RG}+\gamma_3 \dot{SV}+\gamma_4 T\dot{N}$$

Substituting $\dot{P}_1$ and $\dot{P}_2$ from (23) into (24) and (25) we can solve for $\dot{Y}_1$ and $\dot{Y}_2$. Then substituting these expressions in (21) and with further manipulation, we can show the decomposition of the scale effect as follows:

(26) $$Scale\ effect = \sum_{i=1}^{5} decomp_i \qquad i= 1,\ldots,5$$

The detailed expressions for the different components ($decomp_i$) are:

1) effect of changes in cost elasticity and markup

$$decomp_1 = (D_1 + D_2 A\gamma_1\eta_1)(\alpha_1 \dot{\eta}_1+\alpha_1(1+\dot{\theta}_1))$$

$$+(D_2 + D_1 B\alpha_1\eta_2)(\gamma_1 \dot{\eta}_2 + \gamma_1(1+\dot{\theta}_2))$$

2) factor price effect

$$decomp_2 \quad = \sum_i S_i \dot{w}_i (D_1\alpha_1(1+\eta_2 B\gamma_1) + D_2\gamma_1(1+\eta_1 A\alpha_1)]$$

3) effect due to quasi-fixed factors

$$decomp_3 \quad = \sum_{m=K,R} \eta_m \dot{K}_m [D_1\alpha_1(1+B\eta_2\gamma_1) + D_2\gamma_1(1+A\eta_1\alpha_1)]$$

4) exogenous demand effect

$$decomp_4 \quad = \dot{RG}[D_1(\alpha_2 + B\eta_2\alpha_1\gamma_2) + D_2(\gamma_2 + A\eta_1\gamma_1\alpha_2)]$$

$$+\dot{N}[D_1(1-\alpha_2) + D_2 A\eta_1\gamma_1(1-\alpha_2)]$$

$$+\dot{SV}(D_2\gamma_3) + \dot{TN}(D_1\alpha_3 + D_2\gamma_4)$$

5) impact of technology on scale (indirect effect of technology)

$$decomp_5 \quad = \dot{T}\,[D_1\alpha_1(1-\eta_2 B\gamma_1) + D_2\gamma_1(1+\eta_1 A\alpha_1)]$$

where,

$$D_1 = (1+\rho^{-1})(\eta_2 / \sum_{j=1,2}\eta_j)A \qquad \text{where } A = 1/(1-\alpha_1(\eta_1 - 1)$$

$$D_2 = (1+\rho^{-1})(\eta_2 / \sum_{j=1,2}\eta_j)B \qquad \text{where } B = 1/(1-\gamma_1(\eta_2 - 1)$$

The above decomposition reveals the importance of the relation between the price elasticity of demand for the two services and the scale effect. If the two demand functions are completely inelastic $(\alpha_1 = \gamma_1 = 0)$, then the changes in real factor prices or changes in quasi-fixed factors have no effect on output and hence no effect on TFP growth. In this case then the second term (total scale effect) in equation (20) will be zero. To carry out the decomposition of $T\dot{F}P$ as outlined here we need estimates of demand and cost elasticities. The critical elasticities for our calculation are the demand price elasticities, α_1 and γ_1; θ_1 the mark up of price of output j over its marginal cost, the elasticity of demand with respect to per capita income α_2 and γ_2; the output cost elasticities of the two outputs, η_1 and η_2. These elasticities can be obtained from the estimates of the structural model shown in table 2a and 2b.

3. DATA SOURCES AND IMPORTANT ELASTICITIES

3.1 Data Construction

The main source of the data used in this analysis is the telephone industry data published by the Federal Communications Commission (FCC) in their series of annual reports, "Statistics of Communications Common Carriers." This source provides information about all local and long-distance companies who report to the FCC -- those having annual operating revenue in excess of 100 million dollars. Since the other long distance carriers (such as MCI and Sprint) do not report to the FCC in the same level of detail as AT&T does, the FCC industry data excludes these carriers. In addition, no detailed data about these carriers were available from any other source. Hence, the data used in our estimations 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 percent of the long-distance market. Data for a few variables were missing for some years in the sample period 1984-87. These missing data were generated by using information available in other FCC reports, in the US Industrial Outlook and in reports published by the United States Telecommunication Association (USTA) and by the U.S. Bureau of Labor Statistics (BLS).[6]

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. Output price indices for the period 1935-71 were computed from the FCC's data on average revenue per call for local and toll services. These indices were then extended up to 1987 by using information about disaggregated price indices obtained from the 1987 issue of the annual FCC report.

The labor input in the industry was constructed from the industry employment series reported in the FCC reports. Missing observations were generated by using information available in other FCC reports along with information from the U.S. Industrial Outlook and other reports published by the BLS. Our labor input variable is an estimate of the man-hours worked by this work force. The nominal wage rate per hour was obtained by combining information about average hours worked per employee per annum and annual wage compensation data obtained from the FCC annual reports. Our data series for material inputs was obtained 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 perpetual inventory method and using 4.01% depreciation rate. Investment series we obtained from the book values of gross stock of capital from FCC report and was deflated by equipment price deflator (obtained from The Statistical Abstract). 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, deflating them with an appropriate price index, depreciating the stock at an assumed rate of 10% per annum, and lagging the resulting series four periods. The lag is used to reflect the gestation period between R&D expenditure and its impact on the stock of R&D capital.[7]

Investment expenditures on physical capital were deflated by an equipment price index from the Statistical Abstract of the U.S., and R&D expenditures were deflated by an R&D price index from BLS report. The service price or user cost of capital was constructed by using data on the cost of capital, the rate of depreciation, investment goods price deflator and various taxes. A similar procedure was used to construct the service price of R&D capital. All price deflators used in the construction of variables of the model have been normalized to be equal to one in 1982.

In order to avoid double counting of inputs, we separated the labor, capital and material inputs used directly in production from those used in producing R&D stock. This adjustment was made by using weights of different components of aggregate R&D expenditure at the national level (reported by the National Science Foundation). The cost of production was also adjusted in the post-divestiture period to remove the intra-industry receipts and payments of access charges.

Values of all the macroeconomic variables like GNP, population, service sector employment, etc. were obtained from the Economic Report of the President and The Historical Statistics of the U.S. Time series data on the number of existing telephones was obtained from the various FCC annual reports. A time trend is used as a proxy for disembodied technological change. The mean values of cost, revenue, input growth rates, output growth rates and prices of the outputs and inputs of the data used in this study are shown in tables 1a and 1b.

3.2 Descriptive Statistics

The descriptive statistics shown in tables 1a to 1c illustrate the changes in the output mix and changes in toll and local prices as well as changes in quantities and prices of the inputs over the sample period. It is clear that the growth rate of local services has been declining since the early postwar period; real prices of local services have been increasing since 1975. The opposite is the case for toll services; toll services have increased rapidly while its real prices have declined. The growth rates of inputs, shown in table 1b, show that in general, the growth rates of all inputs have declined since the mid-1970's. The exceptions are the R&D stock in the post-divestiture period and materials in the 1981-83 period. In the post-divestiture period the growth rate of input prices, with the exception of materials, have slowed down considerably.

These changes are reflected in the growth rates of total cost and cost shares of the inputs shown in table 1c. The growth rate of total costs has fluctuated over time; it grew at a two digit rate in 1946-55 and 1965-80 periods while it grew at about 9% in the early 1980's and in the post-divestiture period its growth rate has slowed down to about 3%. The share of labor in total cost has steadily declined throughout the period from about 59% in 1935-45 to almost 28% in the post-divestiture period. The share of capital rose until 1955 but since then has held steady, though with a slight declining trend. Share of materials, on the other hand, has been steadily increasing since the beginning of the postwar period and in the post divestiture period the material share is more or less the same as that of labor. Finally, the share of R&D in total cost is very small. It has grown slowly over time from near .005 in 1956-65 to about .008 in 1984-87.

These patterns of output and input growths and changing pattern of output prices, costs and shares indicate significant changes in output and input mix in the US telecommunication industry. These changing patterns have contributed to the growth rate of productivity and have in turn 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.

3.3 Estimation Results

In this paper we jointly estimate the demand and supply side of the US industry by using the time series data for the US telecommunications industry for the period 1935-87. We estimated both the short run and the long run equilibrium models as described in section I. The estimation results of the short run equilibrium model consisting of equation set (9) - (14) are presented in table 2a. The estimation results for the long run equilibrium model, which pertains to equations (9) - (16), are presented in table 2b where equations (15) and (16) represent the conditions of long run equilibrium which pertain to the level of demand for the two fixed factors. The model is non-linear in parameters and variables and therefore it was estimated by the non-linear three-stage least squares (N3SLS) method using a set of instrumental variables. The residuals of the equation set were tested for serial correlation and were corrected for first-order auto-correlation within the estimation of the system of equations. The parameter estimates presented in tables 2a and 2b were generated after the auto-correlation correction. The majority of the parameter estimates are statistically significant and the model fits the data very well.

(a) Estimates of the Demand Parameters

The estimated parameters of the demand equations of the short run and long run models are summarized in table 3. These demand parameters are present in the formula of decomposition which captures the effects of exogenous and endogenous demand shifts on production efficiency. Using the values of these parameters and the associated demand side variables we estimate the effects of the market size on TFP growth.

All the reported parameters are statistically significant. The table shows that at the industry level, both the demand for local service and the demand for toll service are price inelastic. The demand for local service is relatively more inelastic than that of toll service, which agrees with the results of several earlier studies (Lester Taylor (1983), Gatto, Kelijian and Stephan (1988, 1990) etc.). These results conform to the fact that local service is more of a necessity than toll service is.

The number of existing telephones is an important explanatory variable in the demand for local calls than that of toll calls. Results also show that the demand for local service is less sensitive to the growth of real GNP per capita than the demand for toll service. This makes sense because the structure of fees charged for local service has traditionally involved a fairly high fixed monthly access charge which entitles the customer to unlimited local calling. On the other hand, toll service demand is more sensitive to the growth of real GNP per capita. This is because a high portion of toll service demand is generated in industries and institutions whose growth is tied to the growth of national income.

Even if price and income are important factors in determining the demand for toll service, these two variables alone cannot explain the exponential growth in long distance telephone demand in the last two decades. The recent demand for telecommunications services has been increasingly influenced by the information intensity of the economy. The major sectors which are heavily dependent on usage of telephone services are service oriented sectors like banking, finance, telemarketing, airlines-travel, the computer industry, etc. The shift in the sectoral composition of the U.S. economy toward these industries in the last decade has increased the telecommunications intensity of the U.S. economy. To capture the effect of this changing structure of the economy on the demand for telecommunications services, the ratio of service sector employment to non-agricultural employment is included as an explanatory variable in the demand equations. The high positive value of the elasticity of demand for toll services with respect to this variable shown in table 3 indicates that the structural change of the U.S. economy towards a more service-based information-intensive society plays an important role in explaining the increasing demand for telecommunications services in the last decade.

(b) Estimates of the Cost Parameters

On the cost side, as we mentioned above, we estimated two versions of the model: one with and one without imposing the long run equilibrium condition for the two fixed factors of production. In addition, the estimated joint cost function satisfied most of the regularity conditions with a few exceptions.

To calculate whether there has been any over-or-under investment in physical and R&D capital in this industry requires the test of whether the envelope conditions for the two quasi-factors of production hold or not. To test this possibility we employ the procedures developed by Shankerman and Nadiri (1986). The test is based on a comparison of the parameter estimates from equations (9) to (14) which define the short run equilibrium of the variable factors conditional on the given level of stock of fixed factors and the estimates of parameters from equations (9) to (16), which define the long run equilibrium.[8] A general test of joint hypothesis that both the physical capital and R&D capital are in their long run equilibrium levels was decidedly rejected. Based on this evidence, the derived elasticities and other results presented below are based on the estimates of the short run equilibrium model rather than the long run model.[9]

A summary of the estimated scale elasticities and the variable-cost elasticities of different inputs and outputs that we derived from the short and long run models is shown in table 4a and 4b. The elasticity of returns to scale was derived using estimates of the variable cost function (see Caves, Christen and Swansen, 1981 and Bernstein and Nadiri, 1988). That is,

$$\textit{Scale elasticity} = [1 - \sum_{m=1} (\partial \log C^{v_p} / \partial \log K_m)] / \sum_{j=1} (\partial \log C^{v_p} / \partial \log Y_j)$$

where m= K,R and j=1,2. The scale elasticity is equal to the inverse of the sum of the output elasticities of variable cost function after adjusting for possible sub-equilibrium capacity utilization.

The first two columns of table 4a show respectively the short run elasticities of variable cost with respect to an increase in physical and R&D capital stocks. The long run elasticities of industry cost with respect to the increase in these two types of capital are shown in the first two columns of table 4b. These elasticities measure the contribution of these two types of capital to productivity of the industry by reducing the cost of production in the short and long run. What emerges is that in the short run the elasticity of variable cost with respect to physical capital is about 3 to 4 times higher than that with respect to R&D capital. The magnitudes of the elasticities for both types of capital is increasing since 1965, particularly for the R&D capital stock. There is evidence of over-investment in both the physical and R&D capital until the middle of 1970's and significant under-investment in R&D capital in the late 1970's and the 1980's.[10] As an overall observation these two types of capital have had important effect in increasing productivity growth by reducing significantly the cost of production in this industry.

The third and fourth columns in table 4a present the elasticity of the variable cost of production with respect to local and toll services respectively. The results show that an increase in toll output causes a very small increase in variable cost. On average, a 1% increase in toll output production causes an average increase of only a 0.18% in variable cost. In contrast, the cost elasticity of local service is high: on average, a 1% increase in local output causes a cost increase of 0.89%.[11] This high elasticity for local service was even more noticeable in the post divestiture period.

In the post-1970 period, when the cost elasticity of local service increased continuously, the cost elasticity of toll service declined significantly. This is probably a result of the introduction by the FCC of greater competition in the market for toll service, which would be expected to cause faster adaptation of new technology in toll service production compared to that of local service and an increased effort to reduce the cost of production in the long distance service. Completely opposite incentives were likely to have been present under the regulated monopoly situation prevailing in local service. Another reason for the low observed cost elasticity of toll service, especially during the post-divestiture period, was the reductions in access cost charged to AT&T by the Local Exchange companies.

The last column in table 4a represents the overall scale effect. The result shows that the U.S. telecommunications industry experienced increasing return to scale during the entire sample period. However, the value of overall scale elasticity was relatively low in the first few years in the sample and increased in subsequent years. Since the early 1980's the degree of scale has declined somewhat. As mentioned by Waverman (1989), the main reason is that until recent years, industry failed to adopt technologies like microwave transmission, electronic switching, and fiber optic cables, all of which offer great potential for increasing returns to scale.[12]

4. PARTIAL AND TOTAL FACTOR PRODUCTIVITY GROWTH

(a) Partial Productivity Indices

Table 5a shows the growth rate of total output, TFP growth, and partial productivity growth rates for various factors of production for the entire sample period and several sub-periods. The partial and total factor productivity growth indices are plotted in figure 1. The partial productivities are calculated as the difference between the rate of growth of total output and that of a particular factor of production. The growth rate of output in the US telecommunications industry has been very rapid over the entire period; it averaged over 7% per annum. The growth rate of output shown in column (1), has been steadily increasing except for the periods 1945-54 and the post divestiture period 1984-87 when the output growth slowed down from the average of previous period by 5.1% and almost 15.5%, respectively. Labor productivity growth shown in column 2 is also increasing throughout the period except for the periods 1945-54 and 1965-1974. These declines were due to the decrease in output growth in the first period and the substantial increase in employment in the second period. In 1965-74 it is the extraordinary growth of employment that led to a drop of almost 22.3% in labor productivity from the average of the previous period even though the average growth rate of output grew by almost 28.6% between these two periods. Labor productivity has been increasing very impressively since 1974 and particularly after the divestiture it has registered a remarkable growth of over 10% per annum mainly due to the substantial decline in employment since 1981.

The capital, materials and R&D productivity indices show often divergent patterns over the period 1935-87. Capital productivity was negative before 1965 and particularly immediately after World War II when the Bell System, expanded its capital at a very high rate. Since 1965 the capital productivity has increased steadily and it is particularly very high since the divestiture. This increase in capital productivity can be partly attributed to the increased competition in the industry since 1977 when MCI was allowed into the long distance telephone service. Since then competition has been expanded and strengthened in a variety of ways in telecommunications industries.[13]

The materials productivity level has basically declined throughout the period at an average of over 2%. There is some evidence of upward changes in this index. However, materials exert much lesser impact on overall productivity of the telecommunications industry compared to labor and capital with their high shares in total cost. The R&D productivity growth has fluctuated over the period; it has been positive except for the first and last sub-periods with the lowest growth rate in 1965-74. The fluctuation in partial productivities is quite substantial in periods of structural change such as in 1943 and 1984. If these years are removed from the sample, the partial productivities will be much smoother.

The conventional total factor productivity growth rate is shown in the last column of table 5a and also in figure 1. The growth rate of TFP has been positive and very impressive particularly over the period 1965-1983. There was a substantial drop in TFP growth rate in the period 1945-1954 because of the substantial increase in employment and capital expansion. A large decline has been observed since the divestiture mainly due to a decline in measured technological change, scale effect and mark-up as will be noted below. Note that for the period

1975-87 the growth rate of TFP has been much higher than for the period before 1975. The substantial acceleration in TFP growth in 1975-87 may be partly attributed to the increase in the degree of competition in the telecommunications industry. However, in the sub-periods since 1975-87 the rate of conventional productivity growth has diverged significantly. In the period 1975-83, TFP growth was 5.3% but declined substantially in the post-divestiture period to about 2.4%.

(b) Total Factor Productivity Decomposition

Table 5b shows the average annual TFP growth and its decomposition over the entire period and different sub-periods. Columns (a-h) show the percentage contributions of the different sources of TFP growth, and the last column shows the annual average TFP growth. The results indicate important sources of TFP growth in the U.S. telecommunications industry due to the growth of aggregate demand, real input price change, technological change, and non-marginal-cost pricing. Figure 2 shows the movement of TFP growth and its various components over the period 1938-1987.

i. Direct Contribution of Technical Change

Among these four principal sources of total factor productivity noted earlier, the direct impact of technological change was the major contributor (about 50% to 60%) to TFP growth until the middle of the 1970's. It accounted in absolute terms for as much as 1.8% to 2.5% per annum between 1938 to 1974. Since then, the contribution of non-marginal-cost pricing (mark-up) and the contribution of the growth of aggregate demand have gradually increased, while the contribution of technological change has continued to decrease. In addition to the direct impact of technological progress, the indirect impact of technical progress contributed on average about 0.2% of annual growth of TFP growth during the sample period. This indirect effect of technological progress is not often noted in most analyses of TFP growth. In general, the contribution of technical change is identified with pure shift in cost function in most of the TFP decomposition analyses. However, the interaction of scale and technological change also create efficiency gains. Therefore, some contribution of scale is in fact due to scale augmenting technical change. That is some degree of scale of production is necessary to realize the additional input savings from innovation. This effect of technology is classified as part of economies of scale contribution towards TFP growth in table 5b though it could also be classified as part of technical change effect.

What is important to note, as shown in figure 2 is that the rate of technical change when properly measured in the US telecommunications industry is fairly stable and much lower than that of the conventionally measured TFP growth rate. The rate of technical change grew in the early years of the sample. Between 1950-1973 it grew steadily but since 1973 the growth rate of technical change has had a slow decline; the decline has been more rapid since 1980 and particularly in the post-divestiture period. The decline in rate of technical change is noticeable. It is possible that the period 1980s and particularly the period 1984-87 have been a period of transition for this industry and perhaps after the adjustment period is over, the rate of technical change may resume its previous growth. Another possibility is that there are measurement problems that could be addressed with better and more recent data. An important measurement issue is to account for quality changes in both types of services and the quality of capital and labor on the input side. There have been important changes in quality and diversity of telecommunication services and the quality of capital equipment in this industry. Whether the available price deflators and input prices account adequately for the qualitative changes in the outputs and inputs in this industry is an important issue for future research. Further research on this issue and other related issues such as a better index of technology is clearly needed.

ii. Exogenous Demand Effects

As noted earlier, the significant role of the demand side is not often recognized in most TFP studies. Since the growth of demand for communications services is increasing exponentially in the last two decades, the study of this aspect in the context of the telephone industry is very important. The contribution of changes in aggregate demand towards TFP growth has varied over time as can be seen from figure 2 and table 5b. On the average 20-30%

TFP growth can be attributed to changes in aggregate demand. In absolute value, the growth in aggregate demand due to movement of relevant macro economic variables contributed about 0.70- 0.75% of TFP growth per year during the period 1965-87. The contribution from of exogenous demand was significantly higher in the years prior to 1965, except for the 1945-54 period which dropped to about 0.20%. As can be seen from figure 2, the growth of exogenous demand has varied over the period particularly in the early part of the sample. Since 1950 it has been a relatively stable and growing source of TFP growth. In the 1980s however, there is evidence of a slight decline (in absolute terms) in the contribution to TFP growth.

iii. Relative Input Prices

The role of relative factor price inflation in affecting TFP growth is also often ignored in the literature. If the factor prices rise in comparison to the general price level the resulting cost increase would offset potential productivity gains. The converse may also be true i.e., when an industry benefits from lower increases in input price than the economy wide average then it obtains a boost in its productivity growth. As shown in table 5b column 2, and figure 2, the contribution of relative factor prices to TFP growth has been relatively small, mostly negative, but varying over different sub-periods. It contributed to about -0.13% TFP growth per year during the period 1955-64 and nearly 0% per year during 1975-83. Since then the contribution of the relative input price has been positive, accounting for about 0.13% TFP growth per year. These results suggest that in recent years the changes in input price in the US telecommunication industry has been fairly favorable compare to some other industries.

vi. The Effect of Mark-up

The contribution of markup practices was insignificant before the middle of the 1960's, but it increased after that time, and it came to represent over 50% of the measured TFP growth in the later years of the study period. The contribution of mark-up to TFP growth is shown in figure 2. It fluctuates considerably over time and has the same movement as that of the conventional TFP growth. The gap between the TFP growth rate and the mark-up growth has widened in the beginning of the postwar period until the 1970's. Since then this gap has narrowed particularly just prior to the divestiture when the mark-up component dominated the movement of TFP growth. This was due to the decline in other sources of TFP growth as noted earlier.

It is interesting to note the sources of the mark-up changes. Table 6 summarizes the actual price and the incremental costs for two outputs by sub-period.[14] The results are shown in index form setting 1970=1.0. This table shows that for local service, except for a few years in the beginning of the sample period, the actual price was always below its incremental cost. However for toll services in all the years, its actual price was substantially above its incremental cost. After 1970 the cost of local service started to increase, while that of toll service showed a rapid declining trend. 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 mark-up to decline. For the toll service, although the actual price has declined in response to the decline in its incremental cost, the decline in price was less than proportionate. The main source of total mark-up shown in figure 2 is due to the estimated mark-up in toll service which has increased substantially during the last several decades. This clearly indicates that the underlying pricing policy was not marginal-cost pricing. Also, it is clear that although introduction of the competition in toll services has reduced prices considerably since the mid-1970's, and particularly after the divestiture period, it is the substantial decline in incremental cost of provisioning toll services which has been the main factor in increasing the mark-up on toll services and off-setting the negative mark-up on local services.

The above pattern of the mark-up behavior may reflect several underlying activities. The behavior of price and incremental costs of local and toll services before and after the introduction of competition in the long distance services suggest that cross subsidization was present between the local and toll services. This scenario has changed due to the divestiture decree of 1984 which caused the local price to increase rapidly, and thereby reduced the gap between price and incremental cost of that service.

The picture is completely different for toll service. The movement of the incremental cost and price of toll service during the late 1970's and in the 1980's may be the result of many factors. The cost of toll service could have declined for the following reasons:

1) overall technological progress in the communications and information industries within the U.S.
2) advancement of communications and information technology throughout the western world and its spillover effect in the U.S.
3) fast innovation and implementation of advanced technology in provisioning toll services due to competitive pressure
4) reduction in costs encouraged by competition
5) reduction of access costs in post-divestiture period

On the demand side, competition forced the toll price to decline continuously, reducing the profit margin of the firm. This in turn encouraged the firms to reduce cost to maintain their profit margins. In addition to domestic competition, the technological revolution in the information industry in the U.S. and the rest of the world helped to reduce the cost of production. In fact, our results indicate that during the sample period, the rate of decline of incremental cost was faster than the rate of price decline. This behavior of price and incremental cost in toll service increased the markup over cost further which in turn encouraged more competitive entry and also more rapid adoption of the new technology to meet competitive pressure in this industry. This type of interaction of competition and technological advancement is contributing uniquely to the evolution of this industry in the U.S.

v. The Effect of Divestiture

We measure the impact of divestiture on the structure of production by econometric estimation using the time series data for 1935-87 which includes a part of the post-divestiture era. To study the impact of divestiture on cost of production, we included dummy variables with value 1 for the period 1984-87 and 0 for the remaining years in the sample period. The dummy variables were used to capture the shift in cost function and the changes in the demand for inputs. Parameter estimates (H values in Table 2a and 2b) show that divestiture decreased cost in general. In addition, it reduced the elasticity of variable cost with respect to toll service (H2 < 0) while it increased the variable cost elasticity with respect to local service (H1 > 0). The effect of divestiture on employment has been negative (HL < 0), while its effect on demand for R&D and physical capital have though been positive are statistically not significant.

The overall impact of divestiture based on our parameter estimates, is a yearly reduction of about 2.63% of variable cost during 1984-87 . The impact was substantial on demand for labor. During 1984-87, actual employment declined by 10.8% whereas aggregate output grew on average by 6.5% per year during the same period. 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% reduction in employment.[15] Overall TFP growth declined during the period 1984-87 compared to the decade before that.

The divestiture had a differing impact on the cost of producing local and toll services. The coefficients of the dummy variables in tables 2a and 2b suggest that the variable cost of toll service decreased by about 2.8% and that of local service increased by 23.7% due to the impact of divestiture. This suggest that the divestiture has substantially changed the structure of cost in favor of the toll service.

vi. <u>The Overall TFP Growth</u>

The last column in table 5b shows that conventionally measured TFP growth over different sub-periods. Over the whole period, the industry's TFP increased at an average of 3.9% per year. If we analyze the behavior of TFP growth for different time periods, we see that the growth rate per year was very high from the mid-1960's to the beginning of the 1980's. The estimated average annual growth in TFP for 1965-74 is about 4.74% and for 1975-83 is about 5.35%. Table 7b shows that for the period 1965-74, technological change appeared to be the major contributor to high TFP growth, while for the period 1975-83, non-marginal-cost pricing appeared to be more responsible for the high measured growth of TFP.[16] This pattern can be explained in light of historical events in the U.S. telecommunications industry. During the first period 1965-74, AT&T invested significant amounts in building both physical capital and R&D capital which probably boosted technological progress during that period. In the second period 1975-83, in addition to technological progress, the advent of competition and experience of increasing returns to scale in long distance services provisioning also had accelerated reductions in the cost of production and thereby increased the gap between price and marginal cost. TFP growth during 1985-87 was 2.40%, a significant decline when compared to the average rate of the previous twenty years. This decline in TFP growth was due to reductions in the contributions of both technical change and non-marginal-cost pricing to measured TFP growth. The reduced rate of technical change may be due to slow growth in spending on R&D after divestiture, while less-aggressive non-marginal-cost pricing may have arisen as heightened competition forced long distance suppliers to accept lower markups.

5. SUMMARY AND CONCLUSIONS

This paper has provided an integrated framework for studying the dynamic interaction between the demand and the supply side of the US telecommunications industry in influencing the industry's productivity growth under different economic conditions and policy regimes. Our empirical results lead to the following conclusions:

It is clear from the analysis that the traditionally measured TFP growth does not measure the true productivity growth of a multi-product firm when the pricing policy of the firm departs from marginal-cost pricing. The methodology of this study decomposes the traditional productivity into three components-- scale, effect, rate of technical change and mark-up effect. The "true" productivity growth is the sum of estimated scale and rate of technical change i.e. the shift in the production function. It is clear that the rate of technical change has been a critical determinant of productivity growth in this industry. However, its effect has been declining since early 1980 and declined substantially since the divestiture of the Bell System.

The scale effect has been also important and it has counted for about 20-25% of TFP growth. The scale effect was decomposed into several components. The exogenous demand consisting of the effect of macroeconomic variables such as aggregate income and population growth, as well as in the employment structure of the economy, have had important and growing influence on growth of TFP in this industry. The importance of macroeconomic variables and other factors affecting the demand for telecommunications services documented in this study suggests that the "extent" and character of the product market affect the cost structure and efficiency of the production, i.e. the TFP growth. Since macroeconomic variables affect industry TFP growth, it follows that policy decisions, such as monetary and fiscal policies, clearly influence productivity growth in the telecommunications industry.

Another component of the scale effect is the influence of relative input prices which has been very favorable for the US telecommunications industry. Increase in relative input prices, as expected, influences TFP growth negatively. However, the magnitude of this effect has been very small and in post-divestiture the growth rates of input prices has been less than the general prices, thereby contributing positively to growth of TFP. Industry cost inflation has not been a major source of decline in productivity growth in this industry.

As shown in our analysis mark-up is a major component of the traditionally measured TFP growth. This component has to be removed to obtain the "true" TFP growth. The magnitude of the mark-up in this industry has been large but has varied over time. The magnitude of the mark-up throughout the entire period and particularly since 1965 has been due to substantial decline in incremental cost of toll services. The toll services prices has been declining since 1970's partly due to emerging competitive pressure caused by the entry of new suppliers. But the decline in prices have been very small compared to the decline in marginal cost of toll services. The rapid decline of incremental cost of toll service could be the result of rapid technological progress in the information industry in the U.S. as well as in rest of the world. The competitive pressure in the domestic telecommunications market has accelerated the implementation of this new technology in the U.S. Similar phenomena are also taking place in the global telecommunications market, the discussion of which is beyond the scope of this paper. The contribution of local services to the mark-up has been negative throughout the sample period but has been more than offset by the positive contribution of toll services to total mark-up of the industry.

Finally, the 1984 divestiture changed the structure of cost and efficiency of production in the US telecommunications industry in several ways. During the post-divestiture period, the demand for labor declined significantly despite an increased level of output and therefore, labor productivity increased significantly in the post-divestiture period. Divestiture also caused the cost elasticity of toll service to decline significantly whereas that of local service increased indicating the gain in production efficiency of toll service after divestiture. However, the overall TFP growth declined during the post divestiture period primarily because of the declining contribution of technological change towards TFP growth.

[1] For a recent survey, see Good, Nadiri and Sickles (1996) and the references provided.

[2] Cp., e.g., Berndt and Fuss (1981, 1986, 1989), Bernstein and Mohnen (1988, 1991), Caves, Christensen, and Swanson (1980, 1981), Denny, Fuss, and Waverman (1981), Griliches (1988), Hulten (1986), Mohen, Nadiri, and Prucha (1983), Morrison (1985a, b, 1986, 1989, 1990), Nadiri and Prucha (1984, 1990a, b), Nadiri and Schanderman (1981a, b), Oum and Zhang (1991) and Crandall (1989).

[3] Thanks to Dr. Lester Taylor for his valuable suggestions regarding the form of demand functions of two outputs.

[4] See footnote 7 below for details.

[5] For detailed discussion of these results see Nadiri and Nandi (1995).

[6] For details of constructing missing values for various variables and other data measurements see Nadiri and Nandi (1995).

[7] Shankerman and Nadiri (1986).

[8] Based on the methodology developed by Shankerman and Nadiri(1986), let us define C_1 as the parameter vector for equation set (9) to (14) and define C_2 as the parameter vector for equation set (15) to (16). We then partition the parameter vector C_1 as $C_1 = (C_{11}, C_{1K}, C_{IR})$ and C_2 as $C_2 = (C_{2K}, C_{2R})$. Vector C_{11} consists of those parameters that appear in equations (9) to (14) but not in equations (15) and in equation (16) and C_{1K} consists of parameters which appear both in equations (9) to (14) and in equation (15) whereas C_{IR} consists of parameters which appeared both in equations (9-14) and in equation (16). Thus, to estimate the long run equilibrium model equations (9) to (16) we imposed the restriction $C_{1K} = C_{2K}$ and $C_{IR} = C_{2R}$, while short run equilibrium specification imposes no restriction on C_{1K} and C_{1R}. The test statistic is $H = (\hat{C}_1 - \hat{C}_1)'\hat{V}^{-1}(\tilde{C}_1 - \tilde{C}_1) \approx \chi^2_q$ where $\hat{C}_1$ is obtained from equation set (9) to (16) and $\tilde{C}_1$ is obtained from equation set (9) to (14). $\hat{C}_1$ is consistent estimator of C_1 under H_0 but not under alternative hypothesis H_1 whereas $\tilde{C}_1$ is consistent both under H_0 and H_1. The $\hat{V}$ is the consistent estimator of $V = V_S - V_L$ where V_s is the asymptotic covariance matrix of $(\tilde{C}_1 - C_1)$ and V_L is the asymptotic covariance matrix of $(\tilde{C}_1 - C_1)$. The H statistic is asymptotically distributed as a Chi-Square distribution with q degrees of freedom where q is the number of parameters in C_{1K} and C_{1R} in equations (15) and (16) representing the number of parameter restrictions imposed in estimating the long-run model.

[9] The estimated variable cost function satisfied most of the regularity conditions with a few exceptions.

[10] Fixed factors are at their long run equilibrium level when their shadow prices are equal to their rental prices or the opportunity cost of funds used in acquiring those factors. This is the familiar envelope condition. Any divergence between the shadow price and the opportunity cost of capital indicate whether over- or under-investment has taken place in physical and R&D capital stocks. We retrieved the shadow prices of two quasi-fixed factors physical and R&D capital stocks from the estimated variable cost function. The ratio of the shadow prices to their opportunity cost can bet interpreted as the marginal Tobin's q ratios and their divergence from unity would reflect the divergence between observed and equilibrium levels of fixed factors. The result show considerable over-investment in both physical and R&D capital until the middle of the 1970s. The degree of over-investment was highest between 1950 to 1065. This period corresponds to the time when the Bell system invested large amounts of resources on development of new technology which continued throughout the sample period though the degree of over-investment declined substantially over time. See Nadiri and Nandi (1995) for empirical evidence.

[11] For several years in the sample the variable cost elasticitiy for local service production was greater than one.

[12] Overall scale elasticity estimates reported in this paper are derived from the product specific cost elasticities of local and toll services. However, since AT&T, being the major industry player provided local service through many subsidiary local companies, the estimated cost elasticity of local service is likely to contain aggregation bias. If all those local companies expanded at a uniform rate, then the measured cost elasticity would truly reflect the changes in unit cost due to a 1% change in local output. Since it is not very realistic to assume that all local companies grew at the same rate, aggregation bias will be present in our estimation of scale elasticity. A more disaggregate level estimation might give us an alternative estimates of scale properties in this industry and partly such an approach will capture the difference in the growth rates and efficiency of different units of the industry.

[13] For specific test of effect of competition on capital productivity and TFP growth see Oum and Zhang (1991).

[14] The incremental cost for each output is derived from the cost function (9), using the following formula:

$$ICC(Y_i) = (C^{V_P} / Y_i)^{*}(B_i + B_{ii} \log Y_{it} + B_{ij} \log Y_{jt} + B_{Li} \log w_t + \mathrm{B}_{iK} \log K_t + B_{iR} \log R_t + B_{iT} T_t) \qquad \text{for i, j} = 1,2$$

[15] This results are similar to those reported by Crandall (1989) and Oum & Zhang (1991).

[16] As Denny and Fuss and Waverman (1981) have explained, an increase in the mark up of price over cost can contribute to traditionally measured TFP growth, but does not necessarily reflect an improvement in the efficiency of production. For this reason, the traditional measure of TFP growth will be a biased estimator of productivity growth or of efficiency gains specially when significant non-marginal-cost pricing is present.

Descriptive Statistics of Telecommunication Industries* (1935-87)

Table la

Mean values of Revenues and Growth Rates of Output Quantities and Prices

	Mean values of Revenues		Growth Rates					
year	local service rev (ml$)	toll service rev (ml$)	local output	nominal price of local svc	real price of local output	toll output	nominal price of toll svc	real price of toll** output
1935-45	868.26	480.46	0.04767	0.00452	-0.01976	0.08700	0.03140	0.00601
1946-55	2183.73	2366.52	0.06681	0.04577	-0.00615	0.04167	0.05021	-0.00091
1956-65	4953.48	3376.51	0.05004	0.01867	-0.00318	0.08472	0.00579	-0.01576
1966-75	10168 05	9561.39	0.05611	0.03311	-0.02351	0.11822	0.00358	-0.05084
1976-80	20568.27	23078.68	0.05193	0.04045	0.03337	0.12138	0.00856	-0.06300
1981-83	30859.84	36445.35	0.03461	0.08846	0.02025	0.08008	0.06161	0.00500
1984-87	30597.37	46620.61	0.03548	0.09122	0.05445	0.08243	-0.05571	-0.08745

Table lb

Mean values of Operating Cost and Growth Rates in Input Quantities and Prices

	Mean values	Growth Rates							
year	operating cost (ml$)#	captial stock	capital price	R&D stock	R&D price	labor input	labor price	material stock	material price
1935-45	907.99	0.06534	0.01326	0.07674	0.02959	0.04212	0.04549	0.03259	0.03607
1946-55	2663.62	0.09597	0.06556	0.00248	0.06755	0.05389	0.05887	0.05443	0.05917
1956-65	5311.82	0.06499	0.02151	0.04443	0.02618	0.00154	0.046659	0.11828	0.00986
1966-75	12907.70	0.06702	0.05680	0.06567	0.06093	0.02595	0.07816	0.07413	0.06504
1976-80	29569.33	0.03882	0.08083	0.05417	0.08176	0.02253	0.09106	0.09841	0.08315
1981-83	47593.79	0.01489	0.06255	0.05406	0.06660	0.01175	0.06430	0.12936	0.03384
1984-87	58170.65	-0.00584	0.02098	0.07448	0.02860	-0.02743	0.02932	0.09421	0.07016

Source: FCC Reports, Statistical Abstract of U.S. and others

* Industry consists of AT&T and all local exchange companies reporting to FCC

** Nominal price is deflated by GNP deflator to derive real price

Operating cost reported to FCC

Table 1c

Growth Rate of Total Cost and Average Share of Inputs in Total Cost

1935-87

year	growth rate of total cost	share of labor	share of capital	share of material	share of R&D
1935-45	0.089	0.5899	0.3109	0.0900	0.0092
1946-55	0.137	0.5266	0.3989	0.0678	0.0067
1956-65	0.069	0.4089	0.5011	0.0851	0.0049
1966-75	0.119	0.3740	0.4899	0.1303	0.0058
1976-80	0.127	0.3397	0.4827	0.1715	0.0061
1980-83	0.093	0.3173	0.4565	0.2198	0.0064
1984-87	0.032	0.2751	0.4422	0.2749	0.0078

* Total Cost and costs of physical capita, R&D capital and materials are estimated from the original FCC data.

Table 2a: Regression Estimation Results

Parameter Estimates of Cost and Demand Equations

Short Run Equilibrium		
Parameter	Estimate	Std. Error
BO	57.6901	242.80
Bl	-9.6811	6.6820
B2	-0.7077	0.7780
BL	-1.06622	1.1528
BK	0.7306	3.3333
BR	-0.1545	2.2644
BT	0.6811	1.8163
B11	1.0952	0.7434
B22	-0.0545	0.0313
BLL	0.0091	0.0411
BKK	0.3948	0.5387
BRR	-0.1306	0.4946
BIT	0.0044	0.0128
B12	0.2667	0.1313
BIL	0.1343	0.1100
B2L	0.0015	0.0186
B1K	-0.3727	0.5047
B2K	-0.1137	0.0665
B1R	0.2398	0.3389
B2R	-0.0474	0.0424
B1T	-0.0688	0.0426
B2T	-0.0039	0.0051
BLK	0.1064	0.0856
BLR	-0.0611	0.0686
BLT	-0.0164	0.0078
Parameters associated with Structural Dummies (198~87)		
H (Intercept dummy)	-2.7405	1.5822
Hl (Slope dummy with Local service)	0.2372	0.1238
H2 (Slope dummy with Toll Service)	-0.0282	0.0162
HL (Slope dummy with labor)	-0.0468	0.0177
Parameters associated with Demand Equations		
α_0	2.2082	0.6770
α_1	-0.3432	0.0725
α_2	0.1840	0.0859
α_3	0.6206	0.0346
γ_0	1.1252	1.7929
γ_1	-0.8168	0.0710
γ_2	0.6607	0.1053
γ_3	2.1179	0.4494
γ_4	0.4127	0.0754

Equation	variable cost	labor share	rev share of local service	rev share of toll service	local service demand	toll service demand	physical capital demand	R&D capital demand
Adj R2	0.9975	0.9864	0.9592	0.9445	0.9930	0.9964	NA	NA
MSE	0.0014	0.0002	0.0017	0.0013	0.0040	0.0056	NA	NA
DW	1.326	1.734	0.924	1.694	0.117	0.368	NA	NA

Table 2b: Regression Estimation Results

Pammeter Estimates of Cost and Demand Equations

Long Run Equilibrium		
Parameter	Estimate	Std. Error
BO	30.2055	31.8170
B I	-7.4202	5.5166
B2	-0.3001	1.5656
BL	-1.6624	0.8599
BK	1.8477	1.6290
BR	-0.0026	0.3351
BT	0.5590	0.3740
B11	0.4773	0.5215
B22	-0.0273	0.0208
BLL	-0.0033	0.0396
BKK	-0.5136	0.1614
BRR	-0.0134	0.0180
BTT	0.0039	0.0025
B12	0.0998	0.0722
B 1 L	0.0823	0.0907
B2L	-0.0026	0.0102
BIK	0.3338	0.1745
B2K	-0.0235	0.0245
BIR	-0.0045	0.0379
B2R	-0.0117	0.0107
B IT	-0.0595	0.0375
B2T	-0.0016	0.0075
BLK	0.1899	0.0510
BLR	0.0054	0.0120
BLT	-0.0241	0.0050
BKR	0.0195	0.0258
BRT	0.0006	0.0020
G	0.0005	0.0053
Parameters associated with Structural Dummies (1984-87)		
H (Intercept dummy)	-4.0844	1.0886
HI (Slope dummy with Local service)	0.3038	0.1306
H2 (Slope dummy with Toll Service)	-0.0113	0.0086
HL (Slope dummy with labor)	-0.0299	0.0159
HK (Slope dummy with capital)	0.0238	0.0420
HR (Slope dummy with R&D capital)	0.0005	0.0053
Parameters associated with Demand Equations		
α_0	2.7180	0.6605
α_1	-0.3234	0.0707
α_2	0.1224	0.0834
α_3	0.6401	0.0331
γ_0	1.1442	1.9874
γ_1	-0.8950	0.0637
γ_2	0.6456	0.0331
γ_3	1.9671	0.4653
γ_4	0.4254	0.0768

Equation	variable cost	labor share	rev share of local service	rev share of toll service	local service demand	toll service demand	physical capital demand	R&D capilal capilal demand
Adj R2	0.9976	0.9885	0.9617	0.9454	0.9936	0.9962	0.9630	0.6458
MSE	0.0014	0.0001	0.0021	0.0012	0.0037	0.0060	0.0016	0.0000
DW	1.204	1.948	0.802	1.532	0.166	0.318	1.1416	0.576

Table 3

Elasticity of Demand for Local and Toll Services
Short Run and Long Run

	Local Service		toll service	
	short-run	long-run	short-run	long-run
Price elasticity	-0.3432 (0.0725)	-0.3234 (0.0707)	-0.8168 (0.0710)	-0.8949 (0.0637)
Income Elasticity	0.1840 (0.0859)	0.1224 (0.0834)	0.6607 (0.1053)	0.6456 (0.0331)
Elasticity w.r.t no. of existing Telephone	0.6206 (0.0346)	0.6401 (0.0331)	0.4127 (0.0754)	0.4254 (0.0768)
Elasticity w.r.t. Structural change variable	NA	NA	2.1179 (0.4494)	1.9671 (0.4653)

Table 4a
Vanable Cost Elasticities (1938-87)
Short Run Model

year	capital	R&D capital	local service	toll service	scale
1938-44	-0.1078	-0.1300	0.8487	0.2356	1.4858
1945-54	-0.1499	-0.0482	0.9023	0.2354	1.0563
1955-64	-0.0903	0.0034	0.7361	0.2091	1.1502
1965-74	-0.1055	-0.0098	0.8111	0.1638	1.1447
1975-79	-0.1552	-0.0254	0.8678	0.1157	1.2008
1980-83	-0.2037	-0.0438	0.8392	0.0838	1.3587
1985-87	-0.2767	-0.0945	1.0565	0.0167	1.2775
Average	-0.1354	-0.0417	0.8929	0.1775	1.1593

Table 4b
Vanable Cost Elasticities (1938-87)
Long Run Model

year	capital	R&D capital	local service	toll service	scale
1938-44	-0.0609	-0.0229	1.0628	0.2329	0.7423
1945-54	-0.1078	-0.0189	1.1251	0.2384	0.8261
1955-64	-0.2553	-0.0080	1.0924	0.2399	0.9485
1965-74	-0.3527	-0.0122	1.0667	0.2290	1.0509
1975-79	-0.4441	-0.0153	1.0244	0.2147	1.1755
1980-83	-0.4271	-0.0181	0.9214	0.2060	1.3186
1985-87	-0.4048	-0.0216	1.0409	0.1748	1.1739
Average	-0.2457	-0.0144	1.0655	0.2271	0.9821

Table 5a

Growth Rates of Output, Partial Productivities and TFP Growth

Year	Output	Labor	Cap	Material	R&D	TFP
1938-44	6.04	2.93	-0.47	-2.47	-2.57	3.8093
1945-54	5.73	0.18	-3.53	0.40	5.28	2.2013
1955-64	6.31	6.02	-0.22	-4.54	3.14	3.8447
1965-74	8.12	4.68	1.14	0.28	0.91	4.7356
1975-83	7.63	6.36	4.57	-3.42	2.20	5.3505
1984-87	6.45	10.08	7.03	-2.06	-1.00	3.5790
Average	6.76	4.55	0.794	-1.896	1.8228	3.999

Note: Growth rate of output and partial productivities are estimated as follows:

GY = GY1* (REV1/ (REV1 + REV2)) + GY2* (REV2/ (REV1 + REV2))
Labor Productivity = GY - GLAB (growth rate of labor)
Capital Productivity = GY - GCAP (growth rate of capital)
and so on....

Table 5b

Decomposition of Total Factor Productivity Growth
1 938-87

	Sources (%)								
	Scale Effect								Total
year	exogenous demand (a)	factor price (b)	capital adjust (c)	R&D cap-adjust (d)	indirect technical change (e)	residual scale effect (f)	direct technical change (g)	non-marginal cost pricing (h)	TFP (Average annual growth) (i)
1938-44	1.0712	-0.0946	0.0456	0.0874	0.01517	-0.1792	1.8133	0.9109	3.8093
1945-54	0.1903	-0.0667	0.0237	0.0008	0.0758	0.0403	2.3808	-0.4437	2.2013
1955-64	0.9429	-0.1328	0.0458	-0.0011	0.2075	-0.2630	2.4383	0.6071	3.8447
1965-74	0.7051	-0.1082	0.0502	0.0041	0.1898	0.0875	2.4710	1.3361	4.7356
1975-83	0.7634	-0.0320	0.0484	0.0207	0.2007	0.1042	1.7449	2.5002	5.3505
1985-87	0.7279	0.1302	0.0088	0.0626	0.0401	-0.4443	0.3822	1.4946	2.4011
Average	0.7130	-0.0738	0.0403	0.0209	0.1575	-0.0612	2.0607	0.9869	3.8743

*Includes effects of exogenous demand variables GNP, population growth, number of existing telephones and information intensity of the economy.

Table 6

Actual Price and Incremental Cost (Index 1970=100)

(1938-87)

year	incremenatal cost of local svc	price of local service	incremental cost of toll svc	price of toll service
1944	0.3942	0.5065	0.1725	0.6061
1954	0.5221	0.7616	0.3091	0.9514
1964	0.5083	0.9497	0.2004	1.0537
1974	1.0281	1.2197	0.1835	1.1877
1979	1.6512	1.4823	0.1283	1.0811
1983	2.2288	2.0391	0.1044	1.3244
1987	3.1543	2.8790	0.0037	1.0506

Figure 1

Partial and Total Factor Productivity Growth

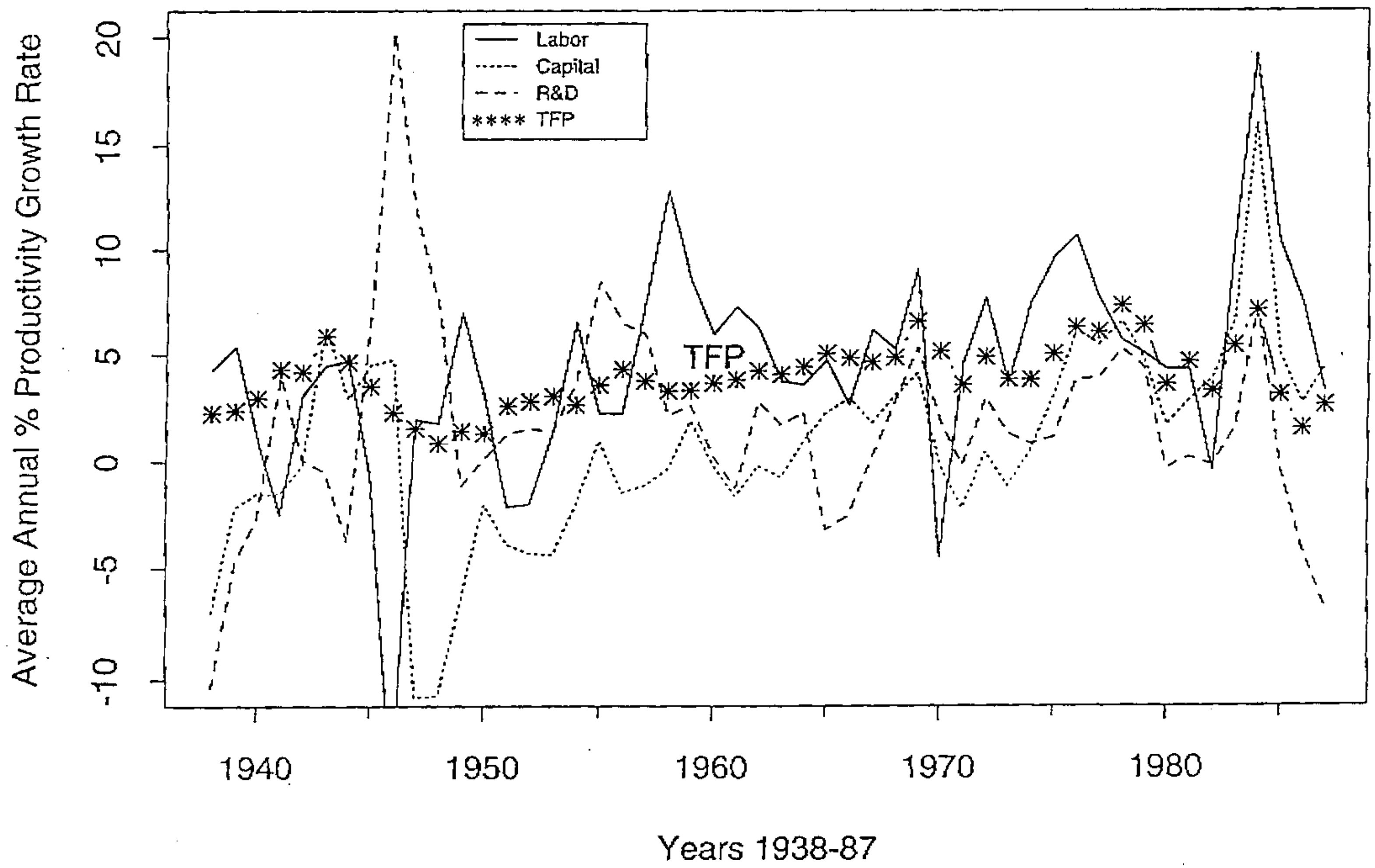
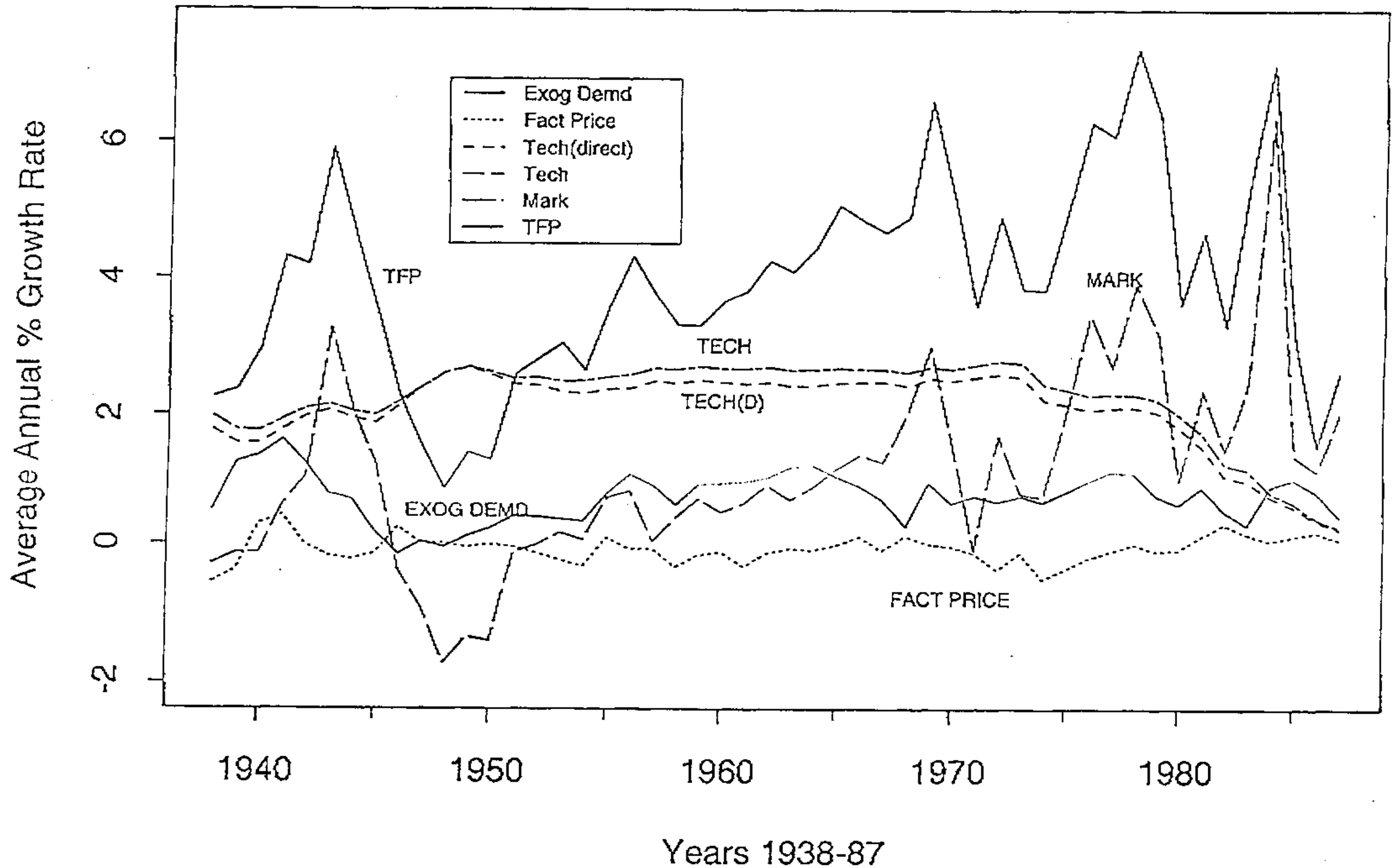


Figure 2

Total Factor Productivity Growth
Different Sources



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