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**COST, PRICING AND PRODUCTIVITY ISSUES IN
TELECOMMUNICATIONS**

by

CHRISTOPHER VAZ

**A dissertation submitted to the Graduate Faculty in Economics in partial
fulfillment of the requirements for the degree of Doctor of Philosophy, The City
University of New York**

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Abstract**COST, PRICING AND PRODUCTIVITY ISSUES IN
TELECOMMUNICATIONS**

by

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Price cap regulation in the telecommunications industry has become more widespread, supplementing or displacing rate-of-return regulation in a number of areas. Under price cap regulation a firm is permitted to increase its price by the amount of the GDP Price Index minus a productivity factor. Much debate centers on an appropriate productivity offset to be used in this calculation, and on the most suitable way by which this productivity factor should be measured.

In many applications of price cap regulation, economists have used what has come to be known as the traditional approach to measuring the change in Total Factor Productivity (TFP). In this approach, aggregate indices of output and input are separately calculated and the growth in TFP is taken as the difference between the aggregate output and input growth rates.

This study examines whether the traditional approach correctly measures a firm's productivity change. It does this by comparing the traditional TFP measure with one based on a model of a local telephone exchange's cost, the Local Exchange Cost Optimization Model (LECOM). It then computes a measure of TFP using the transcendental logarithmic (translog) cost function. This is a flexible function which comprehensively captures the interrelationships between the changing structures of a firm's outputs and inputs. Productivity change is captured by a time-trend variable which measures the change in cost resulting from productivity change as separate from changes in other factors.

Detailed data for 28 cities in the State of Indiana served by The Indiana Bell Telephone Company are used to compare estimates of TFP change using the traditional and the translog approaches. Each provides a measure of TFP change over the same period of time, 1984 - 91, and a significant difference is found. Using the traditional TFP approach, annual TFP growth was found to average 3.7% in this period; using the translog approach, average annual TFP growth was found to be between 7.4% and 8.0%.

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1. INTRODUCTION

1.1 Objective

Rate-base rate-of-return regulation of the telecommunications industry has been criticized since it does not encourage optimal efficiency by the firm.¹ Price cap regulation has been adopted in some jurisdictions because it can potentially provide better market signals to managers and consumers. With such regulation, the price index of a certain basket of services provided by a firm is not allowed to rise by more than a measure of inflation minus a productivity factor. Much debate centers on what appropriate productivity offset should be used in the price cap formula.

A price cap approach tries to simulate the cost conditions and pricing responses of a company as if it were operating in a competitive, unregulated environment. Increased productivity by a firm in a competitive industry would cause the per-unit costs of the firm to decline. Under competition, such declines in unit cost would lead to a reduction in the price of its product. Price cap regulation forces the firm to reflect productivity gains in its prices.

Total Factor Productivity (hereafter TFP) studies are used by regulatory commissions to set the so-called "X-Factor" in the price cap formula. The price

¹ Federal Communications Commission (1992).

cap plan dictates that the price index of a certain basket of services should rise by no more than the amount of some overall price index in the economy [e.g. the Gross Domestic Product Price Index (GDP-PI)] minus the X-Factor (which is based on the TFP measure). The conventional TFP measure is defined as the ratio of aggregate output to aggregate input. The rate of growth of TFP is the difference between the rate of growth of aggregate output and the rate of growth of aggregate input. A problem with such an aggregation is that if a TFP study is conducted for a firm which produces both successful and unsuccessful products, and there is no means of separating the inputs used for the two types of products, the study can significantly understate the amount of productivity growth for the successful product.² This understatement of TFP would enable the firm to be granted a higher price increase, as evidenced by the formula GDP-PI minus TFP, than if the TFP were correctly stated.³ The lower the TFP, the higher the allowed price increase.

As an example, suppose a firm produces two products, X and Y, where X is subject to a rate hearing and Y is a product not yet successfully implemented (hence not relevant to the rate proceedings). Suppose the firm's output growth rate is 6%. A hypothetical computation for the firm producing

² Gabel (1993).

³ This simplified example assumes that $TFP = X\text{-Factor}$. However, the X-Factor is based on the TFP measure and has a slightly more complex form. This issue is discussed along with the presentation of the empirical results in Chapter 7.

only X might, for example, have an input growth rate of 1%, leading to a TFP growth rate of 6% - 1% or 5%. Suppose the firm now begins to use some of its inputs to produce Y. Since the firm has not yet successfully marketed Y, the output growth rate would still be 6%. If an aggregate input index were used, the input growth rate might be, for example, 4%. TFP growth rate would then be 6% - 4% or only 2%. If the GDP price index were 8%, for example, then the firm would be granted a price increase of 8% - 2% or 6% if the TFP were understated as opposed to 8% - 5% or only 3% if the TFP were correctly stated.

Recent TFP studies by Dr. Laurits Christensen (1993) and Dr. William Taylor (1993) used aggregate output and input indices, the traditional approach to computing TFP, and hence might suffer from the problems described above. This dissertation provides an innovative approach to the computation of TFP by combining a cost optimization model with parametric estimation of the cost function. This cost optimization model simulates the firm's long-run cost of producing the relevant products.

The model, LECOM (Local Exchange Cost Optimization Model), was developed by Dr. David Gabel and Dr. Mark Kennet.⁴ It takes the costs of different inputs used to provide different services, the quantities of relevant outputs, detailed area information regarding customer density, locations of

⁴ Gabel and Kennet (1991)

switches, etc. and simulates costs for the firm over the period considered. Data from LECOM for the years 1984 - 1991 will be used to compare TFP growth rates from the Christensen study with those generated by LECOM.

This study computes TFP growth rates based on a cost function approach. A cost function will be estimated, using the 1984 - 1991 data. The rate of productivity growth will then be calculated by multiplying the negative of the partial derivative of the log of the cost function with respect to time by the inverse of the overall returns to scale measure.⁵ It is argued that such estimated productivity growth rates more accurately measure traditional monopoly service productivity gains than those used in the Christensen study. This method will provide regulators the opportunity to explore an alternative approach to setting the X-Factor when determining allowed price changes to firms, and could significantly contribute to the effectiveness of rate regulation.

Gabel and Kennet (1991) used LECOM to evaluate how the cost of service changed with variations in the output mix, input prices, two different kinds of technology - analog versus digital - and the size of the serving area. They further used LECOM in this instance to determine whether the local exchange market was a natural monopoly. This dissertation follows their method of fitting a translog cost function to the data, analyzing the results from

⁵ The overall returns to scale in the case of a multiple output cost function is defined as the sum of the individual cost-output elasticities. See Section 7.1 for a description of this technique.

the regression. In another instance, Gabel (1994) studied the trend of the average cost of production in the local exchange market and examined the feasibility of a price-cap plan. This dissertation adds to this area of research by using the translog cost function to construct the Total Factor Productivity measure. This has also allowed me to separate the effects of overall returns to scale and technological change, and thus to estimate an average X-Factor for the local exchange carrier.

1.2 Outline

Chapter 2 discusses rate-of return and price cap regulation. It explains the two concepts and indicates why price cap regulation is a preferred approach to rate-of-return regulation. Chapter 3 provides a brief review of past studies on Total Factor Productivity in the telecommunications industry. These two chapters provide a description of the workings of this industry in the United States. Chapter 4 explains the LECOM model used in this paper. Important terminology will be discussed as they apply to the issues at hand. Chapter 5 explains how the data set was generated. Chapter 6 briefly describes problems encountered with previous studies and explains how this dissertation attempts to address these problems. Chapter 7 introduces the translog cost function, defines the TFP Index and describes the variables used in the estimation. The

empirical findings will be presented, and the TFP growth rates implied by this study will be compared with those of Dr. Christensen. Using FCC data on TFP growth in the U.S. economy, an average X-Factor for the years 1984 - 91 is also calculated.

2. RATE-OF-RETURN VERSUS PRICE CAP REGULATION

2.1 The Difference between Rate-of-Return and Price Cap Regulation

Under traditional “cost-plus” rate-of-return regulation, a firm is not allowed to earn more than a certain rate of return on its invested capital. The rate of return is described as net revenues (gross revenues minus operating expenses) divided by the value of capital. If the firm’s rate of return is judged to be higher than the cutoff, it is forced to lower its prices; if its rate of return is considered to be lower than the cutoff, the firm is allowed to increase its prices.

Price cap regulation, on the other hand, allows a firm to choose a set of prices for a certain basket of services on the condition that an index of the prices does not exceed some prescribed level. This level is usually taken to be the difference between a widely accepted measure of inflation (such as the Gross Domestic Product Price Index) and an “X-Factor” which is also described as a productivity offset.⁶ For example, if inflation were 5% and the X-Factor were chosen to be 2% then prices could rise by no more than 3%.⁷

⁶ Occasionally an additional adjustment is made for exogenous cost changes that are beyond the control of the firm.

⁷ This simple example does not account for any exogenous cost changes.

The X-Factor is typically chosen by the regulatory agency based on a review of industry productivity studies.⁸

2.2 More on Price Cap Regulation

Price cap regulation was first recommended by Stephen Littlechild and adopted by the British Government in 1984 for the purpose of regulating British Telecom and other privatized monopolies. The FCC adopted price caps for AT&T on July 1, 1989, and for certain Local Exchange Carriers (LECs) on January 1, 1991. The LEC price cap plan is mandatory for the eight largest LECs – the seven Regional Bell Operating Companies (RBOCs) and GTE. It is optional for other LECs. Those LECs electing price caps include United Telephone, Rochester Telephone, The Lincoln Telephone and Telegraph Company, and Southern New England Telephone.⁹

⁸ Other considerations may affect the choice of the X-Factor. For example, New Jersey chose a low X-Factor to encourage infrastructure investment.

⁹ Federal Communications Commission (1994).

2.2.1 Why is Price Cap Regulation preferred over Rate-of-Return Regulation?

The FCC feels that price cap regulation is a preferred approach to traditional rate-of-return regulation because the latter does not encourage optimal efficiency by the firm, while the former creates positive incentives for firms to reduce costs while charging reasonable rates.¹⁰ The FCC further feels that rate-of-return regulation stifles innovation by carriers and also promotes “cost shifting” by carriers that operate in competitive as well as non-competitive markets. Price cap regulation, on the other hand, tries to simulate the environment of a competitive market which rewards those firms that employ cost-reducing technology. At the same time, it reduces the regulatory burden that accompanies rate-of-return regulation. Prices are constrained by a cap, and firms are rewarded by operating more efficiently and offering new services to consumers, not by raising prices. Hence, carriers have incentives to innovate and in the process would provide better-quality and newer services at the lowest possible cost. Consumers also benefit from such regulation, both directly from lower prices and additional services as well as indirectly through lower prices for non-telecommunications goods that are provided by firms that use telecommunications products. Averch and Johnson (1962) also criticized rate-of-return regulation saying that such regulation would drive a firm to

¹⁰ See FCC(1992).

misallocate its resources and substitute between its factors of production in an “uneconomic” fashion.

The FCC, in its Notice of Inquiry regarding “Price Cap Performance Review for AT&T,” (FCC 1992), page 5322, describes its reasons for adopting the price cap plan for AT&T:

The Commission has concluded in the past that rate of return regulation does not encourage optimal efficiency. Under traditional rate of return regulation, the carrier’s allowed profits are computed from its total invested capital, whether or not the carrier is using capital, labor, operational methods, and pricing in the most efficient manner. To maximize its profits, the company has an incentive to manipulate its inputs of capital and labor, without regard to efficiency, and to adopt strategies for investment and pricing based upon what it expects the regulatory agency might wish, not necessarily what best serves its customers and society.

A price cap plan improves on traditional regulation by creating positive incentives for

reasonable rates, innovation, productivity growth and accurate cost allocation, while reducing regulatory burdens. The plan's method is to control prices directly, rather than indirectly by examining whether levels of expenses, investment, and profits are reasonable.

2.2.2 The AT&T Price Cap Plan

Under the FCC's price cap rule for AT&T, adopted in 1989, services were grouped within three service baskets. Basket 1 included residential and small business services (for example long distance services and optional calling plans). Basket 2 included inbound 800 services. Basket 3 included other services used by businesses such as private line, private network, and data transmission services. Rates within each basket (called Actual Prices Indexes or APIs) were not allowed to change, on the average, by more than inflation (then measured by the Gross National Product Price Index or GNP-PI) minus a productivity factor. The resulting figure was also adjusted for a limited set of exogenous cost changes beyond the carrier's control. These exogenous costs included changes in access charges (those charges that are paid by Interexchange Carriers to local telephone companies for "access" to their

networks), taxes, etc. This formula ($\text{GNP-PI} - X \pm \text{exogenous costs}$) defined the Price Cap Index (PCI) for the basket. Within each basket, rate changes in any one year were also limited by rate bands, called Service Band Indexes (SBIs). These SBIs restricted rate changes for individual services within the basket.

In 1990, the FCC realized that the interexchange interstate market had become increasingly competitive. It found that both business services (with the exception of analog private line services) and 800 services (excluding 800 directory assistance) had become effectively competitive. It then “streamlined” its regulation of these services provided by AT&T. Under such streamlined regulation, AT&T needed to file tariffs for such services on only fourteen days’ notice and was not required to file cost support for these tariffs. Moreover, the price caps, bands and floors no longer applied to these services. For those services to which non-streamlined regulation still applied, AT&T was required to file tariffs on 14, 45 or 120 days’ notice, depending on the type of tariff it filed. In January 1995, the FCC further streamlined its regulation of AT&T’s commercial services that it provided small business customers.

All this while AT&T was still considered a dominant carrier in relation to its interexchange competitors¹¹. In September, 1995, AT&T requested the FCC to reclassify it as a non-dominant carrier and hence regulate it in the same

¹¹ A dominant carrier is one that possesses market power.

fashion as its competitors. In October 1995, the FCC did reclassify AT&T as non-dominant. It found that AT&T lacked market power in the relevant interexchange, interstate domestic market. Its findings were based on AT&T's declining market share,¹² the demand elasticity of both business and residential customers, market supply elasticity, and the cost structure, size and resources of AT&T (FCC 1995d). Under this new order, AT&T will be subject to the same kind of regulation as its competitors and will no longer be subject to price-cap regulation. It will also be able to file tariffs on one days' notice and will no longer have to file cost support data.

2.2.3 The Local Exchange Carrier Price Cap Plan

The FCC's price cap plan for the Local Exchange Carriers (LECs) is similar to that originally adopted for AT&T. A LEC's interstate services are grouped within a basket. Again, rates within each basket are not allowed to change, on the average, by more than inflation (measured by the Gross National Product Price Index or GNP-PI) minus a productivity factor, adjusted for exogenous cost changes.

¹² Between 1984 and 1994, AT&T's market share fell from approximately 90% to approximately 55.2% in terms of revenues. (FCC 1995d).

The LEC plan also differs from the AT&T plan in certain ways. The interstate services that the LECs offer are primarily access services used by long distance carriers. LECs also provide other services at the intrastate level. Hence, the LEC service baskets differ from the AT&T baskets of services. The LEC plan has services grouped in four baskets: Common Line, Traffic Sensitive Switched, Special Access, and Interexchange. Common Lines are local loops that connect a subscriber's telephone to the central office. The Traffic Sensitive services, according to the FCC, are a) local transport, b) local switching and c) information. Special Access services are a) audio/video, high capacity/Digital Data service, c) wideband data/wideband analog and d) voice grade/WATS/metallic/telegraph. The LECs were originally allowed to choose between a 3.3% or 4.3% productivity factor¹³ when determining their prices. In this regard, the LEC plan also includes sharing and low-end adjustment mechanisms that are tied to an individual LEC's rate of return performance. Under this original sharing mechanism, if an LEC chose the lower 3.3% productivity factor, thus reducing its rates by 3.3% annually after adjustment for inflation and exogenous cost changes, it was allowed to retain all its earnings up to 12.25% and 50% of all higher earnings up to 16.25%. It had to credit all its earnings in excess of 16.25% to its customers. Alternatively, LECs were allowed to elect a more challenging 4.3% productivity factor. Those that

¹³ These X-Factors included a 0.5% Consumer Productivity Dividend.

chose this higher productivity offset could retain all earnings up to 13.25% and 50% of all higher earnings up to 17.25%. All earnings over 17.25% returned to ratepayers.

In March 1995, the FCC revised its rules for LEC price cap regulation. To begin with, it replaced the use of the GNP Price Index with the GDP Price Index. It also changed the X-Factors in the formula – there is now a minimum X-Factor of 4.0%, with two optional factors at 4.7% and 5.3%. LECs who choose the minimum X-Factor of 4.0% will have to share 50% of their earnings between 12.25% and 13.25% with ratepayers and will be required to return all earnings in excess of 13.25% to the customers. Those LECs choosing the 4.7% X-Factor will face the same sharing requirements as those who chose the 3.3% X-Factor in the original plan. They would be allowed to keep 50% of their earnings between 12.25% and 16.25% and would have to return all earnings in excess of 16.25% to ratepayers. The LECs who choose the highest X-Factor of 5.3% will not be subject to any sharing obligations. The FCC believes that “the opportunity to retain all profits earned may attract the most efficient LECs to this option.” (FCC 1995b).

Three price cap LECs, NYNEX, SNET and US West, have chosen the 4.0% X-Factor. Eight carriers, Ameritech, Bell Atlantic, BellSouth, PacTel, Southwestern Bell, United, Rochester Telephone and Lincoln Telephone, chose

the 5.3% X-Factor. GTE chose 4.0% for eight areas and 5.3% for 38 areas (FCC 1995c).

2.3 The Effects of Price Cap Regulation

The FCC (1993) reported that since its adoption of the price cap plan for AT&T in 1989, their review of AT&T's performance confirmed their belief that price cap regulation represents an improvement over rate-of-return regulation. In spite of an overall inflation in the U.S. economy of 16.1% (over the period of June 30, 1989 - June 30, 1993) the Actual Price Indexes (APIs) for Baskets 1 and 2 fell by 4.4% and 6.1% respectively. For residential customers (who comprise part of Basket 1), rates fell by 5.3%. Overall consumer benefits totaled approximately \$1.8 billion. The Commission also found that AT&T had achieved the productivity growth that the price cap plan was intended to encourage. AT&T managed reductions in the real costs of labor, materials, rents and services, while at the same time modernizing its entire network.

In its Notice of Proposed Rulemaking in the matter of "Price Cap Performance Review for Local Exchange Carriers," the FCC (1994) reports that during the first three years of the LEC price cap plan, all the LECs have kept their APIs at or below the PCIs. None of them has requested rates above the cap.

Overall, LEC interstate access charges are currently \$1.5 billion lower than at the start of price caps, despite overall inflation in the economy of 11.6%. Of this total, \$373 million resulted from the LECs pricing below the cap.

The degree of pricing below the cap varied significantly among the regional carriers' LEC operations. For example, for 1993, Ameritech priced services within its interexchange basket, special access basket, and traffic sensitive basket 14.3, 5.3, and 1.5%, respectively, below the relevant price cap indexes. By comparison, for 1993, NYNEX priced services within its traffic sensitive and special access baskets at the relevant price cap indexes, and priced services within the interexchange basket 0.05 % below the applicable price cap index.¹⁴ These numbers suggest that the interexchange services seem to be subject to more competition than the other services e.g. local transport. This might explain why interexchange services were priced lower relative to their caps than the other services. As competition increases in local transport markets, one might expect rates in such markets to be also lowered relative to their caps.

LEC profits also increased under price cap regulation. The price cap rates in 1991, 1992 and 1993 were targeted for an 11.25% rate of return. The average rate of return for all LECs rose from 11.91% in 1991 to 12.34% in 1992 to 13.12% in 1993 (FCC, 1995a). In fact, FCC (1995a) points out that

¹⁴ All these figures have been taken from FCC (1994).

the high earnings achieved by the price cap LECs suggest that the X-Factor might have been too low, resulting in a not-so-challenging price cap plan.

The FCC also observed that the LECs had introduced a number of new services under price cap regulation. Price cap LECs also “increased the pace of digital switch upgrades, Integrated Services Digital Network...lines, Signaling System 7...capability, and fiber optic transmission facilities.” (FCC, 1995a). Different associations filed comments with the FCC on their perceptions of the effects of price cap regulation. The United States Telephone Association (USTA), an LEC trade association, stated that by 1993, customers gained in excess of \$2.9 billion as a result of the price cap formula, with an additional \$564 million due to LECs pricing below the cap. Southwestern Bell Telephone Company claims that LEC interstate switched access prices declined by 13% under price cap regulation during the same period that output prices in the overall economy rose 12%, thus resulting in a real decline of 25%.

Overall, it seems that price cap regulation is achieving its intended results. Carriers have been reducing their rates, while at the same time reducing their costs (increasing their productivity).

3. TOTAL FACTOR PRODUCTIVITY AND RELATED ISSUES

3.1 The Concept of Total Factor Productivity

Productivity is generally defined as a measure of efficiency by which inputs are combined in order to produce the outputs (goods and services) that society demands. One measure of productivity uses an index of aggregate output divided by the quantity of a single input, usually labor — hence the commonly used term *labor productivity*.¹⁵ The productivity indices are related to some base year, thereby resulting in the rate of growth of productivity over time. Such a simple index, although mathematically easy to construct, is too narrowly defined.

Total Factor Productivity (TFP) is a measure that takes into account all important inputs in the production process. It is used to calculate the residual growth in the outputs that is not accounted for by the growth in the factor inputs. According to Christensen, Cummings and Jorgenson (1975), the concept of TFP was first introduced in a “notable but neglected article by Jan Tinbergen” in 1942, in which he compared growth in real product, real factor input and TFP among France, Germany, the United Kingdom and the United

¹⁵ See, for example, Dean and Kunze (1992).

States, for the period 1870-1914. In 1947, Stigler developed his concept of TFP independent of Tinbergen's study. Since then, significant research in the area of Total Factor Productivity has been conducted by Solow (1957), Kendrick (1961), Christensen and Jorgenson (1969) and others. Nadiri and Schankerman (1981), Denny, Fuss and Waverman (1981), Cowing, Small and Stevenson (1981) and others have measured TFP with the cost-function model, using the principles of duality theory i.e. using the cost-function dual of the production function. The cost function is an alternative but equivalent specification of the technology embodied in the production function, under the assumption of cost minimization. The cost function can be used to test for scale economies, technical change, input substitution, homogeneity in prices of inputs, etc. and has been used extensively in many studies in its most popular form, the transcendental logarithmic (translog) form.

3.2 The Traditional Calculation of Total Factor Productivity

This section shows how one might calculate an index of TFP, using an appropriate transformation function of inputs and outputs. Berndt (1980) is of the opinion that certain assumptions need to be met in order to use this approach. Other economists, for example Caves and Christensen (1980), think otherwise.

Suppose there exists a transformation function relating inputs (X_1, X_2, \dots, X_n) and outputs (Y_1, Y_2, \dots, Y_m) at different points in time, t .¹⁶ Let us denote this general transformation function as

$$H(Y_{1t}, Y_{2t}, \dots, Y_{mt}; X_{1t}, X_{2t}, \dots, X_{nt}; t) = 0,$$

where H satisfies the appropriate differentiability and curvature properties.

Denoting a scalar index of the m outputs at time t as Y_t , a scalar index of the n

inputs as X_t , and the proportional rates of growth as \dot{Y} and \dot{X} ,¹⁷ the TFP

index is normally calculated as

$$TFP = \dot{Y} - \dot{X} \quad (3.1)$$

What conditions should be placed on

$H(Y_{1t}, Y_{2t}, \dots, Y_{mt}; X_{1t}, X_{2t}, \dots, X_{nt}; t)$ in order to measure TFP in the

above manner? A set of sufficient conditions, according to Berndt, is that there

exist consistent indices of aggregate output and of aggregate input. It is thus

assumed that $H(Y_{1t}, Y_{2t}, \dots, Y_{mt}; X_{1t}, X_{2t}, \dots, X_{nt}; t)$ can be written in the

homothetic weakly separable form¹⁸

¹⁶ See Berndt (1980).

¹⁷ $\dot{Y} = \frac{d \ln Y}{dt}$ and $\dot{X} = \frac{d \ln X}{dt}$

¹⁸ A function of outputs and inputs is said to be homothetic if it can be written as a separable function in the outputs and the inputs.

$$\begin{aligned}
& H(Y_{1t}, Y_{2t}, \dots, Y_{mt}; X_{1t}, X_{2t}, \dots, X_{nt}; t) \\
& = H^*[G^*(Y_{1t}, Y_{2t}, \dots, Y_{mt}), F^*(X_{1t}, X_{2t}, \dots, X_{nt})] \\
& = H^{**}[G^{**}(Y_t), F^{**}(X_t, t)],
\end{aligned}$$

where Y_t and X_t are “composite goods” or “consistent aggregates.” If in addition it is assumed that the homothetic separability is of the additive type, we can specify the familiar production function

$$G(Y_t) - F(X_t, t) = 0, \text{ or } G(Y_t) = F(X_t, t)$$

Separability of this kind has two important implications.¹⁹ Firstly, separability implies that outputs are produced “jointly,” i.e. that the cost of producing one kind of output depends on the amounts of the other kinds of outputs that are produced. Secondly, it implies that the ratios between output prices are independent of factor prices. Many economists have used equation (3.1) to measure TFP.²⁰ Caves, Christensen and Diewert (1982) have proved that separability is not required to compute TFP using the discrete approximation of equation (3.1), which is shown later in equation (3.7).

¹⁹ See Hall (1973) for further details.

²⁰ Cowing and Stevenson (1981) have an excellent collection of papers on productivity measures in regulated industries.

3.2.1 The Divisia and Törnqvist Indices of Total Factor Productivity

Denny, Fuss and Waverman (1981) have also explained how to construct the conventional index of TFP, as shown in equation (3.1). Denoting an aggregate output index by Y , the rate of growth of aggregate output can be defined as

$$\dot{Y} = \sum_k \frac{P_k Y_k}{R} \dot{Y}_k \quad (3.2)$$

where P_k is the price of output k , Y_k is the quantity of output k and $R = \sum_k P_k Y_k$ is the total revenue. The rate of growth of an aggregate index of inputs, X , can be defined as

$$\dot{X} = \sum_i \frac{w_i X_i}{C} \dot{X}_i \quad (3.3)$$

where w_i is the price of input i , X_i is the quantity of input i and $C = \sum_i w_i X_i$ is the total cost. If TFP is defined as Y/X , the rate of growth of TFP can be defined as

$$\dot{TFP} = \dot{Y} - \dot{X} \quad (3.4)$$

Equations (3.2) to (3.4) are in terms of instantaneous changes. In order to modify them for data that are obtained in discrete time intervals, the so-called Törnqvist approximations are:

$$\Delta \log Y = \log \left\{ \frac{Y_t}{Y_{t-1}} \right\} = \frac{1}{2} \sum_k (r_{kt} + r_{k,t-1}) \log \left\{ \frac{Y_{kt}}{Y_{k,t-1}} \right\} \quad (3.5)$$

where Y_{kt} is the quantity of output Y_k that is produced in time period t , $r_{kt} = P_{kt}Y_{kt} / \sum_k P_{kt}Y_{kt}$ is the revenue share of output Y_k in the total revenue in time period t , and

$$\Delta \log X = \log \left\{ \frac{X_t}{X_{t-1}} \right\} = \frac{1}{2} \sum_i (s_{it} + s_{i,t-1}) \log \left\{ \frac{X_{it}}{X_{i,t-1}} \right\} \quad (3.6)$$

where X_{it} is the quantity of input X_i that is used in time period t , $s_{it} = w_{it}X_{it} / \sum_i w_{it}X_{it}$ is the cost share of input X_i in the total cost in time period t . Then, the Törnqvist approximation to equation (3.4) is

$$\Delta TFP = \Delta \log Y - \Delta \log X \quad (3.7)$$

Denny, Fuss and Waverman (1981) note that this TFP index requires assumptions of constant returns to scale, pricing at marginal cost, absence of a rate of return constraint and cost-minimizing behavior. When these assumptions are not satisfied, they say that “conventional indices of total factor productivity growth include not only the technical effect of technical change...but also the effects of nonconstant returns to scale and market imperfections.” They also state that aggregation of outputs using prices will be incorrect if the prices of many services do not equal their marginal costs. They

add that “the index requires careful interpretation when the above assumptions are incorrect.”

3.2.2 Some Specific Studies on Total Factor Productivity Using the Traditional Approach and the Cost-Based Approach

Caves, Christensen and Trethaway (1981) studied the productivity of 11 U.S. trunk air carriers²¹ during the years 1972 - 1977 and found that the average annual growth rate of productivity ranged from 0.7% (for Pan Am) to 5.2% (for Delta, which has taken over most of Pan Am's routes). They had to assume, in order to use the index-number approach, that the structure of production exhibited constant returns to scale and that the output prices were proportional to their marginal costs. They believed that these assumptions were reasonable. The assumption of constant returns to scale in the case of telecommunications will be examined later.

Cowing, Small and Stevenson (1981) calculated various alternative measures of TFP for 81 electric utility firms during the years 1964 - 1975, among them being the traditional index-number measure, as measured by equation (3.7).²² They calculated four variants of this measure, which they

²¹ American, Braniff, Continental, Delta, Eastern, National, Northwest, Pan Am, TWA, United and Western.

²² They also calculated a cost-based measure which is described below.

called “unadjusted,” “adjusted for capacity utilization,” “adjusted for returns to scale” and “adjusted for capacity utilization and returns to scale.” They found an average annual TFP growth rate of 1.0169% for the first type of measure, 1.0200% for the second, 1.0135% for the third and 1.0168% for the fourth. This leads them to conclude that “with regard to the industry averages, little appears to be gained by using more refined exact-index-number TFP measures.” (Cowing, Small and Stevenson (1981), p.172, ¶ 1.) Employing rank-order TFP comparisons of firms, however, leads them to the conclusion that differences among the measures with regard to individual utilities are more pronounced.

Denny, Fuss and Waverman (1981) calculated the conventional TFP measure for Bell Canada over the years 1952 - 1976, and found the average annual rate to be 3.35%, which they compared with Canada’s manufacturing sector’s performance of only 1% per year (this comparable index for the manufacturing sector was apparently presented in a 1979 paper by J. May and M. Denny: “Post-war Productivity in Canadian Manufacturing,” *Canadian Journal of Economics*, 12, pp. 29 - 41). They further decomposed the index to show the effects due to departures from marginal cost pricing, nonconstant returns to scale, technical change and rate-of-return regulation. The decomposition led them to the conclusion that scale economies contributed

approximately three-fifths of the growth in TFP, while non-marginal cost pricing and technical change contributed approximately one-fifth each.²³

Christensen (1993) calculated the traditional TFP index [equation (3.7)] for Indiana Bell for the years 1984 - 1991. Using an aggregate output measure for six services²⁴ and an aggregate index measure for three inputs,²⁵ he found that aggregate output grew at an average annual rate of 4.4%, aggregate input grew at an average annual rate of 0.7% and TFP grew at an average annual rate of 3.7%. Christensen's study will be examined in more detail later, when his results are compared with those of this dissertation.

Cowing, Small and Stevenson (1981), as mentioned in footnote 22, also calculated a cost-based measure of TFP. They estimated a translog cost function²⁶ along with input cost share equations for a base period, 1964. They then used the base-period parameters to project the costs that might have existed in later years had there been no technological advancement and calculated the TFP index as

$$TFP_{0,t}^C = C'_p / C'_a \quad (3.8)$$

²³ They however caution the reader, saying "interpretation of these results as indicating a dominance of scale economies must be tempered by the recognition of substantial difficulties encountered in measuring outputs and portraying technical change." (Denny, Fuss and Waverman (1981), p. 212, ¶ 2.)

²⁴ Local service, interstate access service, intrastate access service, toll service, directory advertising and other miscellaneous services.

²⁵ Labor, capital and materials.

²⁶ The form of the translog cost function is specified in Chapter 7.

where C_t^a is actual costs in period t and C_t^p are the costs in period t predicted from the base-period parameters and the values of the relevant independent variables in period t . They found an average TFP value of 1.1427%.

Gollop and Roberts (1981) used a translog cost function in order to identify the sources of economic growth for 11 electric utilities in U.S. during the years 1958 - 1975. They found a drastic decline in the productivity growth, with the average annual rate decreasing from 6.5% in 1958 - 66 to - 4.2% in 1973 - 75. They decomposed the sources of the productivity growth into technical change and economies of scale effects, and found that the contribution due to scale economies declined on average from 1.8% in 1958 - 66 to nearly zero in 1973 - 75. The average annual contribution of technical change declined from 4.7% to - 4.1% between the same two periods.

Caves, Christensen and Swanson (1981) calculated productivity growth for Class I U.S. railroads in the period 1955 - 74. They too used a cost function approach and, relaxing the assumption of total cost minimization, assumed instead that "the firm minimizes the cost of employing variable factors subject to predetermined levels of quasi-fixed factors." They found an average annual rate of productivity growth of 1.8% for the 1955 - 74 period.

Ying and Shin (1993) performed an interesting analysis of the impact that the divestiture of AT&T had on the productivity of LECs, including the RBOCs. They too used the translog specification of the cost function, and

estimated the cost function along with factor share equations using Zellner's seemingly unrelated regressions technique. Their data set consisted of 46 large LECs for the years 1976 - 87, of which 22 were BOCs. They used a dummy variable for divestiture with a value of 0 for 1976 - 83, and 1 for 1984 - 87. Their first-order parameter estimate for this variable was negative and significant, indicating that costs have decreased. They found that, on average, BOCs realized larger percentage declines in costs than non-Bell firms. In 1987, for example, Bell firms' costs were, on average, 4.1% lower than they would have been absent divestiture while non-Bell firms had costs that were, on average, 3.52% lower than otherwise.

Taylor (1993), appearing on behalf of The Diamond State Telephone Company, summarized certain TFP studies of the telecommunications industry. Table 3-1, adapted from his testimony, shows the TFP growth rates for the U.S. industry as a whole and for the communications sector for different periods.

Table 3-1: TOTAL FACTOR PRODUCTIVITY GROWTH

	Period Growth Rate
US INDUSTRY	
BLS: 1948 - 1990	1.44%
APC: 1948 - 1987	1.71%
LRC (2): 1951 - 1987	1.24%
COMMUNICATIONS INDUSTRY	
APC: 1948 - 1987	3.97%
AT&T: 1947 - 1979	3.21%
LRC (1): 1947 - 1979	3.22%
LRC(2): 1951 - 1987	3.17%
RWC: 1960 - 1987	3.37%

- (1) BLS: Bureau of Labor Statistics, Multiproduct TFP Growth, U.S. Private Business.
- (2) APC: American Productivity Center, Multiproduct TFP Growth, U.S. Private Business, Communications Industry.
- (3) LRC(1): L.R. Christensen, Testimony filed in United States v. AT&T, Civ. Action No. 74-1698 (D.D.C. filed November 20, 1974).
- (4) AT&T: Bell System Productivity Study: 1947 - 1979, September, 1980.
- (5) LRC(2): L.R. Christensen, "Total Productivity Growth in the U.S. Telecommunications Industry and the U.S. Economy: 1951 - 1987," filed in North Dakota Public Service Commission Case No. PU-2320-90-149, October 1, 1990.
- (6) RWC: R.W. Crandall and J. Galst, "Productivity Growth in the U.S. Telecommunications Sector: The Impact of the AT&T Divestiture," The Brookings Institution, July, 1990.

Source: Adapted from Taylor (1993), Attachment 3, Page 7.

4. LOCAL EXCHANGE COST OPTIMIZATION MODEL (LECOM)

4.1 Background

LECOM was first developed by Dr. David Gabel and Dr. D. Mark Kennet in 1991, as part of a study conducted for the National Regulatory Research Institute [Gabel and Kennet(1991)]. Telephone companies have studied the nature of the cost function for many years using three different kinds of costing methods: 1) accounting, 2) engineering and 3) statistical studies, with each kind of method having its advantages and disadvantages.²⁷ LECOM combines engineering process models with optimization techniques to calculate the cost of the local exchange network's facilities. It searches for the optimal combination and location of switching machines that minimize the cost of producing a certain level of output. It can also be used, however, for calculating the costs of producing certain outputs, for a given location and number of switches, which is what LECOM is used for in this dissertation. What follows is a discussion of certain topological aspects of the local exchange network and descriptions of how LECOM is configured to operate in this topology.

²⁷ See Gabel and Kennet (1991), pages 1 and 2, for a brief description of these methods.

4.2 Network Topology

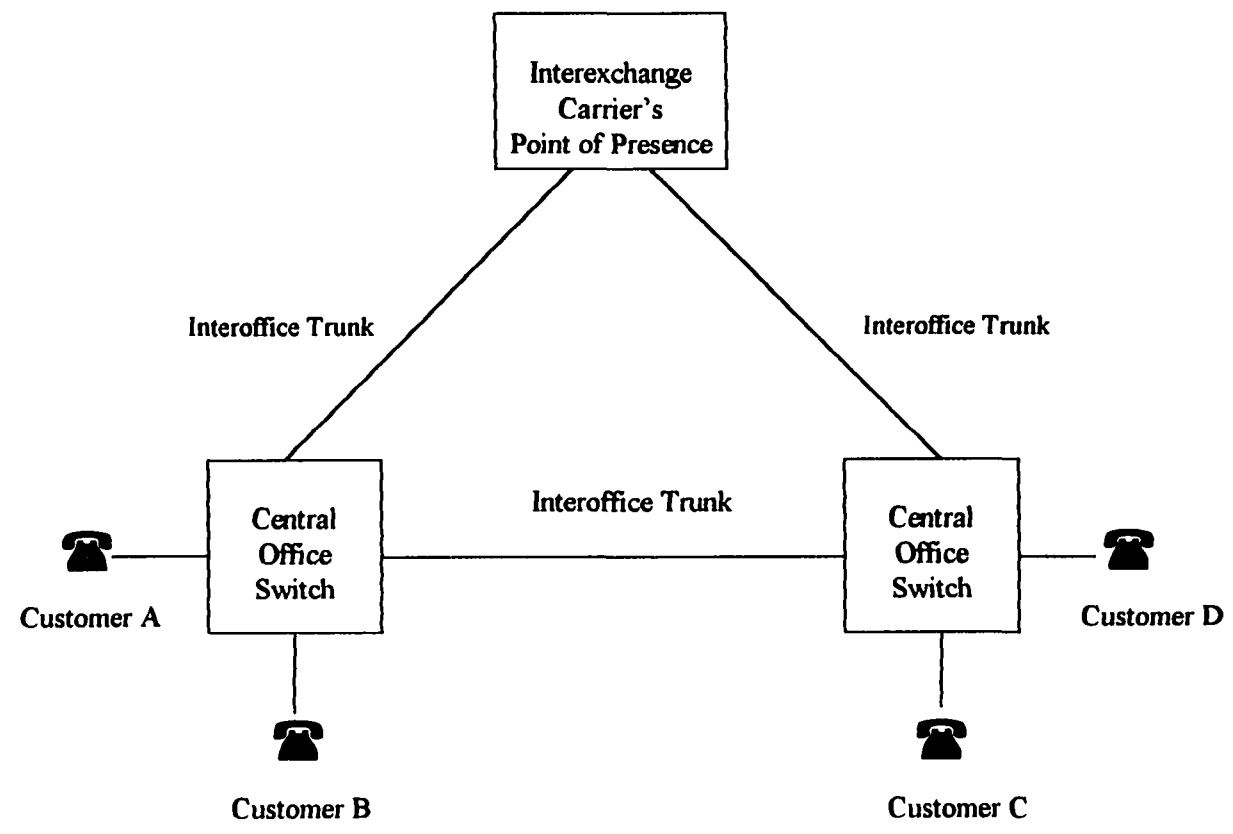
The local exchange carrier's network has three primary kinds of facilities: 1) the local loop, 2) interoffice trunks and 3) central offices. The local loop connects a telephone subscriber's premises to the local exchange's central office. The central office houses a switch that connects a subscriber's line to another subscriber connected to the same switch or to an interoffice trunk. An interoffice trunk connects one central office to another or to an interexchange carrier's (a long-distance carrier such as AT&T) point of presence (see Figure 4-1).

4.2.1 The Local Loop

Before digital switches were employed, the local loop facilities consisted primarily of copper wires which were of four different gauge sizes: 26, 24, 22 and 19-gauge.²⁸ The size of the installed copper wire depends on the distance between the customer's premises and the central office. The smaller diameter

²⁸ The larger the gauge, the smaller the diameter of the wire. For example, 26-gauge wire is smaller in diameter than 19-gauge wire.

Figure 4-1: NETWORK TOPOLOGY



Source: Gabel and Kennet (1991)

wire (which is also less expensive) was used for customers that were located close to the central office. The main disadvantage of these larger gauge wires was that they had a higher resistance than the smaller gauge wires. LECOM makes use of a file that contains different cable lengths and the appropriate mixture of gauges that are required for copper wires, based on the engineering practices of the industry.²⁹

Each central office serves a number of serving areas, which typically include between 350 and 600 subscribers. A serving area is connected to the central office by means of a feeder plant, and subscribers are connected to the feeder plant by means of distribution plant. LECOM calculates the costs of feeder and distribution.

Lines that enable communication among subscribers are installed either overhead or under the ground. Overhead or aerial cables are more exposed to natural elements than cables that are placed under the ground. Cables that are laid under the ground are of two types - those that are *buried* directly into the ground in open fields or in suburban and rural areas, and those that are pulled through underground ducts or conduits (commonly referred to as *underground cable*). In the latter case, the system consists of relatively closely spaced manholes that are connected by ducts or conduits in which the cables are

²⁹ This file and others will be described in more detail later.

installed. LECOM makes use of data that reflect the annual cost of deploying underground and buried cable.

4.2.2 Advancements in the Local Loop

4.2.2.1 *Subscriber Loop Carrier*

In the past, analog technology was the dominant technology. Today, digital switching is the norm. The central office used to serve as the sole means by which subscribers' lines were concentrated into the switched network. With the advent of digital switching, this concentration can occur much closer to the customer, for example at a *remote switching center*. Bell Operating Companies usually use SLC-96[®] (Subscriber Loop Carrier) for such line concentration.³⁰ Recent technology has made the replacement of copper wires with fiber optic cables possible. LECOM uses a file which provides cost data to determine the economic crossover point for subscriber loop carrier on copper versus subscriber loop carrier on fiber.

³⁰ Subscriber Loop Carrier is a "pair-gain" system which reduces the need for additional cable by increasing the number of customers served by existing facilities.

4.2.2.2 Remote Switches

Remote switches affect the cost of the local loop. Remote switches are connected to a large *host switch* (the DMS-100) which can terminate approximately 5,700 lines. The DMS-100 host switch is capable of handling approximately 300,000 busy-hour calls during a busy season. A remote can either handle calls that originate and terminate on the remote, or can pass all calls through to the host. The deployment of remote switches can reduce the distance between the customer and the central office.

4.3 Local Exchange Traffic

Local exchange traffic could either originate and terminate on the same switch in a central office or be carried along trunks between central offices. The former type of traffic is called *intraoffice* and the latter is *interoffice*. The proportion of interoffice and intraoffice calls varies among communities. In rural areas, for example, a central office might typically serve all customers in a community with a single switch, thus local traffic would only be intraoffice traffic. In larger cities, the local exchange carrier would deploy more than one switch. LECOM uses the proportions of interoffice and intraoffice calls as inputs when calculating costs.

4.4 Overall Description of LECOM

The programs in LECOM take the annual costs of capital, labor and materials as inputs. They also read in stylized information about different cities (the size of the city, location and number of switches, location and number of wire centers, number of customers in each serving area, etc.). The software is written and compiled in Turbo Pascal, a product of Borland International, Inc. A host of other variables is contained in the data files which will be described in Chapter 5 - for example, the calling capacity of a DMS-100 digital switch. Using these data for 28 cities and for the years 1984 - 1991, I used LECOM to calculate the cost of providing five different kinds of outputs.

5. THE DATA SET

The data set consists of information on 28 cities in the State of Indiana that are served by Indiana Bell, for the period 1984 - 1991, the same years for which Christensen conducted his study. The data files for each city contain detailed map designs, information on many variables and trunking information. One of the LECOM modules converts a map of a wire center with degrees of latitude and longitude as its grid into a file that is usable by the LECOM programs. This map file contains detailed information on the different areas served by the wire center. Other data files that are used contain information on cable lengths and the appropriate mixture of gauges required for copper wires, trunk costs, the costs of remote switching machines, costs of DMS-100 components, costs of distribution loops, etc. There is a file that contains the locations of digital switches in each city and the type of switch that is being used (e.g. DMS-100 or remotes). The interested reader can refer to Gabel and Kennet (1991) for a more detailed description of the files that are used by LECOM. It is to be noted that this author was given the files containing the cost and other data such that the actual data values were not readable, since the data are considered proprietary.

5.1 The Outputs

I assume that the local exchange carrier “produces” four outputs: exchange switched service, toll switched service, local private line service and toll private line service. Access to the telephone network is needed when exchange or toll switched service is provided. Hence, although access is not technically an output (in the sense that it is not a product that is valued by and unto itself but rather a derived demand) it is evidently a component of costs, and will be included in the calculations and analysis. Let

Y_1 = exchange switched service

Y_2 = toll switched service

Y_3 = local private line service

Y_4 = toll private line service

Y_5 = switched access

5.2 Generating the Data

For each city LECOM reads in the relevant data files and computes the costs of providing the five services as a baseline case for each of the years 1984 - 1991. The rates of growth for the five services over this time period are the

same as those Christensen used, so that I can meaningfully compare my estimates of total factor productivity with those that he obtained. Section 5.3 describes how I use these growth rates.

I also specify a certain percentage by which outputs might vary so that LECOM can calculate the costs of providing levels of output other than the baseline case. This helps evaluate how changes in output would affect the costs of production. As an example, consider the year 1984, and a 20% change in output.³¹ LECOM will first calculate the costs of providing a certain $(Y_1, Y_2, Y_3, Y_4, Y_5)$ combination - this is the baseline combination. It will then tweak Y_1 by 20% i.e. it will calculate the cost of providing $(Y_1 + 0.2 Y_1, Y_2, Y_3, Y_4, Y_5)$. It will also calculate costs of providing different combinations of the outputs, e.g. $(Y_1, Y_2 + 0.2 Y_2, Y_3, Y_4, Y_5)$, $(Y_1, Y_2, Y_3 + 0.2 Y_3, Y_4, Y_5)$ and so on, thus resulting in 32 different combinations, including the baseline.³²

In order to introduce price variation in the data set, I also “tweak” the price vectors within LECOM. Since there are three prices (labor, capital and materials) I could technically have $2^3 = 8$ combinations of price vectors. This is known as a factorial experiment where the effects of a number of different

³¹ This 20% change in output is used so that LECOM can simulate the costs of providing different combinations of services, and is not connected in any way to Christensen’s growth rates described earlier.

³² Since there are five services that are provided, the total number of combinations that are provided by the baseline, then respectively changing only one service, two services and so on, is: ${}^5C_0 + {}^5C_1 + {}^5C_2 + {}^5C_3 + {}^5C_4 + {}^5C_5 = 32$.

factors (in this case three) are investigated simultaneously. The data so constructed might not be strictly orthogonal. Another design, called the “central composite design” allows the addition of $(2 \cdot 3 + 1)$ factor combinations, resulting in a total of $(2^3 + 2 \cdot 3 + 1) = 15$ combinations. This has been done before, in Kennet, Heyen and Gabel (1995). The numbers should be chosen such that the radius from the center point is equal for all points in the data set. The interested reader can refer to Cochran and Cox (1957) for more details. Table 5-1 shows the price vectors used. There are a total of 15 price variations for each city in each year. Thus, there are 32 observations for each price variation, as described in the previous paragraph, times 15 price variations times 28 cities, which equals 13440 observations for each of the eight years 1984 - 1991, resulting in a grand total of 107520 observations in the entire data set. LECOM provides the total costs along with the quantities of each service and other data. I will use these data, including the prices of capital, labor and materials and other relevant indicator variables to estimate a cost function, which will enable me to compute estimates of Indiana Bell’s total factor productivity over the time period considered.

5.3 Growth Rates of Outputs

LECOM needs three growth rates to be specified in order for it to perform its calculations. These are the growth rate of access lines, the growth rate of interoffice trunks and the growth rate of ccs per access line.³³ For the growth rate of access lines and the growth rate of interoffice trunks, I have made appropriate adjustments to the data used by Christensen in his study of Indiana Bell productivity (Christensen, 1993). These adjustments are described below.

Christensen studied the impacts of providing six services:

- (1) Local Service
- (2) Interstate Access Service
- (3) Intrastate Access Service
- (4) Toll Service
- (5) Directory Advertising
- (6) Other Miscellaneous Services

Table 5-2 shows the indices that he constructed for the six services for the years 1984 - 1991 and also shows the revenue shares for the six categories of service. When specifying the rate of growth of access lines, I have used Christensen's

³³ ccs = one hundred calling seconds.

data on local service and calculated the rates of growth of the index of local service. Table 5-3 shows my calculations. For the rate of growth of interoffice trunks, I used the data on interstate access, intrastate access and toll service. I calculated the growth rate of a weighted Törnqvist index of the indices for these three services using adjusted revenue shares as weights, with the formula:

$$\ln\left(\frac{Q_t}{Q_{t-1}}\right) = \sum_i .5(r_{i,t} + r_{i,t-1}) \ln\left(\frac{Q_{i,t}}{Q_{i,t-1}}\right)$$

where $Q_{i,t}$ is the index for service i (in year t) in Table 5-2, and $r_{i,t}$ is the adjusted revenue share of service i in year t . The revenue shares need to be adjusted because I am considering only three categories out of the six services for interoffice trunks. Hence the revenue shares need to be adjusted when used as weights to ensure that the weights add to one. Table 5-4 shows the rates of growth for this index of interoffice trunks. In order to justify using these three categories as a proxy for calculating the growth of interoffice trunks, I tested a hypothesis that the growth of toll usage is equal to the growth rate of exchange usage, using data from the *Statistics of Communications Common Carriers*, for the years 1984 - 93. The two-tailed p-value for the test was 0.8433, and thus led to the non-rejection of the hypothesis.

For the growth rate of ccs per access line, I will assume a 1% yearly increase. This assumption is consistent with studies on telephone usage. Once

I have declared these inputs to LECOM, it performs the calculations for the different cities and gives me the cost and output data, as outlined above.

Table 5-1: PRICE VECTORS USED TO INTRODUCE PRICE VARIATION

Price of Labor	Price of Capital	Price of Materials
0.9	1	1
0.9	1	0.9
0.9	0.9	1
0.9	0.9	0.9
1	1	1
1	1	0.9
1	0.9	1
1	0.9	0.9
0.95	0.95	0.95
0.95	0.95	1.1
0.95	0.95	0.8
0.95	1.1	0.95
0.95	0.8	0.95
1.1	0.95	0.95
0.8	0.95	0.95

Table 5-2: INDICES FOR THE SIX INDIANA BELL SERVICE CATEGORIES

Year	Local Service	Interstate Access	Intrastate Access	Toll Service	Directory Advertising	Miscellaneous
1984	1.000	1.000	1.000	1.000	1.000	1.000
1985	1.026	1.161	1.051	0.995	0.891	1.000
1986	1.057	1.158	1.132	1.068	0.927	0.796
1987	1.077	1.318	1.247	1.164	0.979	0.704
1988	1.128	1.450	1.362	1.271	1.145	0.447
1989	1.155	1.684	1.367	1.310	1.190	0.625
1990	1.228	1.813	1.477	1.360	1.234	0.566
1991	1.267	1.863	1.512	1.414	1.229	0.474
Revenue Shares for the Six Indiana Bell Service Categories						
Year	Local Service	Interstate Access	Intrastate Access	Toll Service	Directory Advertising	Miscellaneous
1984	.479	.201	.079	.116	.061	.065
1985	.476	.214	.091	.106	.051	.063
1986	.484	.207	.091	.120	.050	.048
1987	.461	.222	.093	.129	.052	.044
1988	.456	.228	.097	.132	.060	.028
1989	.450	.228	.096	.126	.060	.040
1990	.465	.214	.100	.123	.061	.037
1991	.482	.207	.092	.125	.061	.032

Source: Christensen (1993), Exhibit LRC-3, page 1.

Table 5-3: CALCULATION FOR RATE OF GROWTH OF LOCAL SERVICE

Year	Local Service Index	Growth Rate using natural logarithms
1984	1.000	
1985	1.026	2.6
1986	1.057	3.0
1987	1.077	1.9
1988	1.128	4.6
1989	1.155	2.4
1990	1.228	6.1
1991	1.267	3.1
AVERAGE RATE OF GROWTH		3.4

Table 5-4: CALCULATION FOR RATE OF GROWTH OF INTEROFFICE TRUNKS

Year	Törnqvist Index
1984	
1985	8.583781
1986	3.427924
1987	10.99252
1988	9.174811
1989	8.459685
1990	6.439766
1991	2.974212

6. PROBLEMS WITH PREVIOUS STUDIES

6.1 Introduction

This chapter briefly describes some of the problems encountered with previous studies and then explains how my model attempts to handle some, if not all, of these problems.

Researchers have studied various aspects of the telecommunications industry (for example, productivity, the extent to whether a telephone utility is a natural monopoly, etc.) and have encountered all kinds of problems in doing so. The most important problems with such studies have been the choice of data and the level of aggregation. One of the issues that has plagued researchers for years has been the choice of an appropriate proxy for technological change, which leads to a shift of the cost function. Such change results in a reduction in the costs of providing certain outputs (or an increase in productivity). Economies of scale (movements along the cost function) also aid in reducing costs, and if one were not able to correctly identify technological change, how then could one separate the effects of scale economies and technological change on total productivity? Researchers have in the past used various proxies for technological change, such as research and development expenditures, the number of access lines served by electronic switching machines, etc. These

proxies have come under criticism, as not being “good measures of technological change.”³⁴

As Gabel and Kennet (1994) note, “the analysts have also had trouble controlling for input prices and constructing output indexes for the various categories of services.” Many studies, Christensen’s (1993) included, have used an aggregate index of outputs and inputs in order to compute TFP measures. As noted in Chapter 1, a problem with such an aggregation is that if a TFP study is conducted for a firm which produces both successful and unsuccessful products, and there is no means of separating the inputs used for the two types of products, the study can significantly understate the amount of productivity growth for traditional successful monopoly services. Aggregation of outputs and inputs also rests on the assumption that the firm in question is characterized by constant returns to scale.³⁵ However, this characterization is not true in the case of telecommunications firms. Christensen, Christensen and Schoech (1981) applied a neoclassical cost function to time series data for the Bell System for the years 1947 - 1979. They found scale economies in the range of 1.4 to 1.6, indicating increasing returns to scale. Nadiri and Schankerman (1981) presented two models with scale elasticities of 1.75 and 2.12. Their data were of the Bell System as well. Nowhere in Christensen’s

³⁴ See Evans (1994), page 9.

³⁵ See Denny, Fuss and Waverman (1981), pp. 192 - 199 for a discussion of this point.

(1993) testimony has he noted that he has assumed anything about constant returns to scale; even if he had, it would have been a significantly incorrect assumption.

Researchers have commonly used accounting costs to conduct telecommunications studies. A telephone utility's "reported costs may not be the costs that a firm would incur under competitive market conditions. Hence, there is a need to review data which reflects economic [costs]."³⁶

Evans (1994) has also noted that many studies use flexible functional forms, such as the translog, which will be employed here, that have too many parameters to be estimated with short time series. He mentioned that various estimates were simplified by setting many coefficients to zero.

6.2 Advantages and Disadvantages of Local Exchange Cost Optimization Model (LECOM)

LECOM tried to address the data and other problem described above. As noted in Chapter 4, LECOM combines engineering process models with optimization techniques to calculate the cost of the local exchange network's facilities. It can search for the optimal combination and location of switching machines that minimize the cost of producing a certain level of output. It can also be used for calculating the costs of producing certain outputs, for a given

³⁶ Gabel (1994), page 5.

location of the switching machines and the number of customers that are attached to each of these machines. I have used this option. Since LECOM uses algorithms that reflect the actual engineering standards used in the telephone network, it automatically incorporates the utility's technology in the model – the number of switching machines, switch locations, etc. It also contains data that are used to compute the point above which it is more economical to use digital line carrier on copper or fiber, rather than straight copper, for feeder cables. When estimating the cost function with the data generated by LECOM, a time trend variable is used to further reflect technological changes that may not have been accounted for already. The data generated from LECOM are then used to compute a total factor productivity index that will not suffer from aggregation problems discussed in Section 6.1 in that the cost of providing the relevant outputs will be calculated and used in the estimation of the TFP index.

The LECOM-generated data in estimating the cost function also make it possible to separate the effects of technological change and scale economies on the productivity growth of the local exchange carrier. The LECOM approach does not suffer from aggregation problems present in Christensen's study, summarized in Section 1.1. The costs of producing the relevant outputs and hence the carrier's productivity as related to only those outputs can be identified.

An advantage of fixing the location of the central offices is that LECOM calculates the economic cost of providing services under the current network configuration. As Dr. Gabel (1994) notes:

[T]his methodology ... does not comport with the notion that, in the long run, all inputs to the production process are variable. This costing methodology, like that of telephone company cost studies, assumes that the current location and number of switching machines is fixed...To the extent that the current configuration is not optimal, the assumption of fixed switch locations will result in an overestimation of the cost-of-production, compared to the true, long-run cost of production.

With regard to Evans' contention about the large number of parameters estimated in many studies, the present method does not suffer from this problem since there are sufficient degrees of freedom. There are a large number of parameters to estimate (65) but there are also a very large number of observations (107519). Like Evans, I also feel that most studies are guilty of "restricting" their models by setting many of the coefficients or sums of them equal to zero. This could lead to an incorrect specification of the model. The

preferred approach is to “test” the hypotheses about the parameters, not to “restrict” and so the model presented here does not lay any restrictions at all on the parameters.

7. THE TRANSLOG COST FUNCTION AND THE EMPIRICAL FINDINGS

7.1 The Translog Cost Function

The translog was first introduced by Christensen, Jorgenson and Lau (1973). They claim that it provides a second-order approximation to any twice-differentiable cost function. The form of the translog that I use is:

$$\begin{aligned}
 \ln C = & \ln \alpha_0 + \sum_{i=1}^3 \alpha_i \ln P_i + \sum_{k=1}^5 \beta_k \ln Y_k + \phi_S \ln S + \phi_t t \\
 & + \frac{1}{2} \sum_{i=1}^3 \sum_{j=1}^3 \alpha_{ij} \ln P_i \ln P_j + \frac{1}{2} \sum_{k=1}^5 \sum_{l=1}^5 \beta_{kl} \ln Y_k \ln Y_l + \frac{1}{2} \phi_{SS} (\ln S)^2 \\
 & + \frac{1}{2} \phi_{tt} t^2 + \sum_{i=1}^3 \sum_{k=1}^5 \delta_{ik} \ln P_i \ln Y_k + \sum_{i=1}^3 \delta_{iS} \ln P_i \ln S + \sum_{i=1}^3 \delta_{it} (\ln P_i) t \\
 & + \sum_{k=1}^5 \delta_{kS} \ln Y_k \ln S + \sum_{k=1}^5 \delta_{kt} (\ln Y_k) t + \delta_{St} (\ln S) t + \varepsilon
 \end{aligned} \tag{7.1}$$

where:

- C = total cost
- Y₁ = exchange switched service
- Y₂ = toll switched service
- Y₃ = local private line service
- Y₄ = toll private line service
- Y₅ = switched access
- P₁ = price of labor
- P₂ = price of capital
- P₃ = price of materials
- S = serving area
- t = time
- ε = disturbance term

Homogeneity of degree 1 in input prices and symmetry implies:

$$\sum_i \alpha_i = 1; \sum_i \alpha_{ij} = 0; \sum_j \alpha_{ij} = 0; \sum_i \delta_{ik} = 0; \sum_i \delta_{is} = 0; \sum_i \delta_{it} = 0;$$

$$\alpha_{ij} = \alpha_{ji}; \beta_u = \beta_{ik};$$

Following Fuss and Waverman(1978), and Caves, Christensen and Swanson (1981), the Total Factor Productivity Index can be defined as

$$-\frac{\partial \ln C}{\partial t} \left\{ \sum_{k=1}^5 \frac{\partial \ln C}{\partial \ln Y_k} \right\}^{-1} \quad (7.2)$$

where the first term is a measure of technological change and the second term (in the parentheses) is the overall “returns to scale” measure in the case of the multiproduct cost function. It is the inverse of the sum of the individual cost-output elasticities. These two components will enable me to separate the effects of technological progress and returns to scale, as previously mentioned in Chapter 6. Chapter 3 indicated that Denny, Fuss and Waverman (1981) noted that construction of the TFP index, as used by Christensen, requires an assumption of constant returns to scale. Chapter 6 mentioned that Christensen’s (1993) testimony has not made any explicit assumption about constant returns to scale. If the results from this study show that there are increasing or decreasing returns to scale, this casts further doubt on the TFP index computed by Christensen. For the translog defined in equation (7.1),

$$\frac{\partial \ln C}{\partial t} = \phi_t + \phi_n t + \sum_{i=1}^3 \delta_{it} (\ln P_i) + \sum_{k=1}^5 \delta_{kt} (\ln Y_k) + \delta_{st} (\ln S) \quad (7.3)$$

and

$$\begin{aligned} \sum_{k=1}^5 \frac{\partial \ln C}{\partial \ln Y_k} = & \sum_{k=1}^5 \beta_k + \sum_{k=1}^5 \beta_{kk} (\ln Y_k) + \sum_{k=1}^5 \sum_{l=1}^5 \beta_{kl} (\ln Y_l) \\ & + \sum_{i=1}^3 \sum_{k=1}^5 \partial_{ik} (\ln P_i) + \sum_{k=1}^5 \partial_{ks} (\ln S) + \sum_{k=1}^5 \partial_{kt} t \end{aligned} \quad (7.4)$$

7.2 Data Generated by LECOM and Empirical Results

As noted in Chapter 4, LECOM reads in detailed information for each city and performs simulations for the years 1984 - 91. The variables generated by LECOM that are used in the estimation of the translog cost function are the total cost, the quantities of the five outputs (access, exchange switched service, toll switched service, local private line service and toll private line service) and the size of the area served. Christensen's input price data are used and a time variable is added. Since the central composite design was used to introduce variation in the input prices, Christensen's "baseline" input price data have been accordingly adapted to be consistent with the price variations.

LECOM has a fixed technology set, and the input price variation has been used to proxy for technological innovation. Such technological change will also be embodied in the annual carrying charge factors for capital that are

used by LECOM in the data files. In addition, the time variable has also been added to capture any technological variation that may be possibly unaccounted for. This is consistent with Shin and Ying (1992), Evans and Heckman (1983) and others. Christensen's study has used the values of capital taken from Form M reports filed with the FCC for the study years. Variations in the different vintages of capital and productivity that are reflected in Christensen's study are not captured by LECOM. However, given that his methodology and the one used in this dissertation are two alternative ways of computing the TFP indexes, variations in the way in which technological change is reflected are inherent in the two approaches. The aggregation problems in Christensen's study were discussed above in Section 1.1. Later in this Section, problems relating to his implicit assumption of constant returns to scale are discussed.

All variables except time are divided by their means. One reason for doing this is that it is a means of scaling the data such that the order of magnitude is approximately the same for all left- and right-hand-side variables. If the right-hand-side (X) values are large in absolute value, the $X'X$ values will be even larger. Inverting $X'X$ will then give rise to relatively small numbers and the precision of the estimates will suffer. Another reason is that, by dividing by the means, the coefficient estimates can be directly interpreted as the first and second order derivatives at the mean value. Hence, equation (7.3), evaluated at the means, becomes:

$$\frac{\partial \ln C}{\partial t} = \phi_t + \phi_{\pi} t \quad (7.5)$$

and equation (7.4), evaluated at the means, becomes:

$$\sum_{k=1}^5 \frac{\partial \ln C}{\partial \ln Y_k} = \sum_{k=1}^5 \beta_k + \sum_{k=1}^5 \partial_{kr} t \quad (7.6)$$

The variables used in the estimation are:

cost=log cost;
 acc=log of access lines;
 exch=log of exchange switched service;
 toll=log of toll switched service;
 lcpl=log of local private line service;
 ttpl=log of toll private line service;
 pl=log of price of labor;
 pk=log of price of capital;
 pm=log of price of materials;
 area=log of serving area;
 accsq=(acc*acc)/2;
 exhsq=(exch*exch)/2;
 tollsq=(toll*toll)/2;
 lcplsq=(lcpl*lcpl)/2;
 ttplsq=(ttpl*ttpl)/2;
 plsq=(pl*pl)/2;
 pksq=(pk*pk)/2;
 pmsq=(pm*pm)/2;
 areasq=(area*area)/2;
 timesq=(time*time)/2;
 accexch=acc*exch;
 acctoll=acc*toll;
 acclcpl=acc*lcpl;
 accttpl=acc*ttpl;
 exchtoll=exch*toll;
 exchlcpl=exch*lcpl;
 exchttpl=exch*ttpl;
 tolllcpl=toll*lcpl;
 tollttpl=toll*ttpl;
 lcplttpl=lcpl*ttpl;

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plpk=pl*pk;
plpm=pl*pm;
pkpm=pk*pm;
placc=pl*acc;
plexch=pl*exch;
pltoll=pl*toll;
pllcpl=pl*lcpl;
pltlpl=pl*tlpl;
pkacc=pk*acc;
pkexch=pk*exch;
pktoll=pk*toll;
pklcpl=pk*lcpl;
pktlpl=pk*tlpl;
pmacc=pm*acc;
pmexch=pm*exch;
pmtoll=pm*toll;
pmlcpl=pm*lcpl;
pmtlpl=pm*tlpl;
plarea=pl*area;
pkarea=pk*area;
pmarea=pm*area;
pltime=pl*time;
pktime=pk*time;
pmtime=pm*time;
acctime=acc*time;
exchtime=exch*time;
tolltime=toll*time;
lcpltime=lcpl*time;
tlpltime=tlpl*time;
accarea=acc*area;
excharea=exch*area;
tollarea=toll*area;
lcplarea=lcpl*area;
tlplarea=tlpl*area;
areatime=area*time;

```

When estimating the cost function, one observation was dropped from among the 107520 observations. The data file for this observation seemed to be incomplete and LECOM is programmed to report unusual values when this

happens. Hence, the findings are based on 107519 observations. I estimated the translog using pooled time series and cross-section data for the eight years 1984 - 91.³⁷ The results are reported in Table 7-1.

The reader should be aware that since the data are generated from a combination of actual data and simulation, they are, in effect, "pseudo data." Griffin (1977a and 1977b) has also generated pseudo data for the electric power and petroleum refining industries and used these data to estimate a statistical cost function. He has touted the merits of such data relative to conventional time series data by mentioning that these data overcome the problems of multicollinearity and a limited sample range. He too has varied input prices by certain multiples for the process of generating the data. Serafica (1996) has nicely summarized the responses of other economists, like G.S. Maddala and R. Blaine Roberts, to using a single-equation model to represent the information contained in the data. Serafica mentions that Maddala and Roberts point out that the error terms are not stochastic but rather are approximation or calibration errors. This has also been pointed out by Gabel and Kennet (1991), who state that "interpreting calibration errors probabilistically seems problematic" and "[any statistics] should be interpreted with caution."

³⁷ Other issues, for example, testing parameter restrictions across cities, the use of the translog as a local versus global approximation, could be incorporated into the analysis but are not discussed here as they are not part of the central issue of this dissertation. They will be incorporated in future research.

Note, in Table 7-1, that the first order coefficients on the outputs “exchange” and “toll” are negative. At first glance the reader might construe that these have the wrong signs. Greene (1993) has an example where he presents a translog production function of log of output regressed on log of labor, log of capital, and squared and interaction terms. His model is:

$$\ln Y = \beta_1 + \beta_2 \ln L + \beta_3 \ln K + \beta_4 \frac{\ln^2 L}{2} + \beta_5 \frac{\ln^2 K}{2} + \beta_6 \ln L \ln K + \varepsilon$$

where L and K are labor and capital, respectively, and Y is output. In estimating this equation, he gets a negative coefficient on ln K. He mentions: “note that the coefficient on ln K is negative. We might conclude that the estimated output elasticity with respect to capital now has the wrong sign. However, this would be incorrect. In the translog model, the capital elasticity of output is

$$\frac{\partial \ln Y}{\partial \ln K} = \beta_3 + \beta_5 \ln K + \beta_6 \ln L$$

If we insert the coefficient estimates and the mean values for ln K and ln L...the result is 0.5425 [which is positive].” Similarly, in the model presented in this dissertation, the cost-output elasticities with respect to “exchange” and “toll” also contain the squared and interaction terms. The relevant derivatives were computed and positive numbers were obtained.

Of the 65 parameters (excluding the constant term), 37 are significant at the 1% level, 2 are significant at the 5% level and 3 are significant at the 10%

Table 7-1: TRANSLOG ESTIMATES

Variable	Estimate	S.E.	t-value	p-value(2 tail)
INTERCEP	0.304419	0.004187	72.713	0.0001
ACC	0.824717	0.011042	74.688	0.0001
EXCH	-0.246995	0.009913	-24.915	0.0001
TOLL	-0.267742	0.009913	-27.008	0.0001
LCPL	0.248115	0.01052	23.585	0.0001
TLPL	0.232535	0.010888	21.357	0.0001
PL	0.442170	0.028142	15.712	0.0001
PK	0.378257	0.020101	18.818	0.0001
PM	0.159082	0.028199	5.641	0.0001
AREA	0.186699	0.001348	138.531	0.0001
TIME	-0.059143	0.002252	-26.267	0.0001
ACCSQ	-0.039105	0.057651	-0.678	0.4976
EXCHSQ	-0.702392	0.043621	-16.102	0.0001
TOLLSQ	-0.694540	0.043621	-15.922	0.0001
LCPLSQ	0.149278	0.044779	3.334	0.0009
TLPLSQ	-0.250997	0.054765	-4.583	0.0001
PLSQ	0.079278	0.091751	0.864	0.3876
PKSQ	-0.600420	0.069574	-8.630	0.0001
PMSQ	-0.152122	0.092624	-1.642	0.1005
AREASQ	-0.010218	0.000572	-17.851	0.0001
TIMESQ	-0.005563	0.000603	-9.218	0.0001
ACCEXCH	0.252084	0.025286	9.969	0.0001
ACCTOLL	0.241315	0.025286	9.544	0.0001
ACCLCPL	-0.365324	0.035155	-10.392	0.0001
ACCTLPL	-0.012256	0.041089	-0.298	0.7655
EXCHTOLL	-0.008559	0.041476	-0.206	0.8365
EXCHLCPL	0.239911	0.023801	10.080	0.0001
EXCHTLPL	0.257681	0.02489	10.353	0.0001
TOLLLCPL	0.238639	0.023801	10.026	0.0001
TOLLTLPL	0.257626	0.02489	10.350	0.0001
LCPLTLPL	-0.264486	0.033762	-7.834	0.0001
PLPK	0.326223	0.087047	3.748	0.0002
PLPM	0.030624	0.157159	0.195	0.8455
PKPM	0.352354	0.089425	3.940	0.0001
PLACC	-0.003483	0.043996	-0.079	0.9369
PLEXCH	0.004286	0.039343	0.109	0.9133
PLTOLL	0.000303	0.039343	0.008	0.9938
PLLCPL	0.022245	0.041397	0.537	0.5910
PLTLPL	-0.024987	0.043298	-0.577	0.5639
PKACC	0.047279	0.036805	1.285	0.1989

Variable	Estimate	S.E.	t-value	p-value(2 tail)
PKEXCH	-0.012119	0.032921	-0.368	0.7128
PKTOLL	0.006323	0.032921	0.192	0.8477
PKLCPL	-0.086432	0.03472	-2.489	0.0128
PKTLPL	0.047058	0.036248	1.298	0.1942
PMACC	-0.006278	0.044396	-0.141	0.8875
PMEXCH	0.008357	0.039703	0.210	0.8333
PMTOLL	0.005367	0.039703	0.135	0.8925
PMLCPL	-0.000710	0.041777	-0.017	0.9864
PMTLPL	-0.006057	0.043688	-0.139	0.8897
PLAREA	-0.002859	0.004859	-0.588	0.5563
PKAREA	-0.012129	0.004066	-2.983	0.0029
PMAREA	0.001433	0.004903	0.292	0.7702
PLTIME	0.006805	0.007408	0.919	0.3583
PKTIME	-0.023134	0.005288	-4.375	0.0001
PMTIME	-0.006344	0.007418	-0.855	0.3925
ACCTIME	-0.001910	0.002753	-0.694	0.4880
EXCHTIME	0.004445	0.002463	1.805	0.0711
TOLLTIME	0.004432	0.002463	1.799	0.0719
LCPLTIME	-0.009951	0.002603	-3.822	0.0001
TLPLTIME	-0.000204	0.002711	-0.075	0.9401
ACCAREA	0.081462	0.003204	25.425	0.0001
EXCHAREA	-0.186114	0.002934	-63.432	0.0001
TOLLAREA	-0.180352	0.002934	-61.468	0.0001
LCPLAREA	0.118279	0.003162	37.410	0.0001
TLPLAREA	0.102512	0.003178	32.253	0.0001
AREATIME	0.004296	0.000305	14.095	0.0001

R-squared = 0.9882

Adjusted R-squared = 0.9882

F-statistic for joint hypotheses of homogeneity = 10.361

(p-value = 0.0001)

Table 7-2: TFP RESULTS

Year	TFP	TFP Index	Growth Rate
1984	0.075	1.000	
1985	0.082	1.100	9.5
1986	0.090	1.200	8.7
1987	0.097	1.301	8.1
1988	0.105	1.403	7.6
1989	0.113	1.506	7.1
1990	0.120	1.610	6.7
1991	0.128	1.715	6.3
Average			7.7

Table 7-3: COMPARISON WITH CHRISTENSEN'S RESULTS

YEAR	TFP INDEX		GROWTH RATE	
	This Study	Christensen's Study	This Study	Christensen's Study
1984	1.000	1.000		
1985	1.100	1.061	9.5	6.0
1986	1.202	1.066	8.7	0.4
1987	1.301	1.087	8.1	1.9
1988	1.403	1.122	7.6	3.2
1989	1.506	1.198	7.1	6.5
1990	1.610	1.248	6.7	4.1
1991	1.715	1.293	6.3	3.6
Average			7.7	3.7

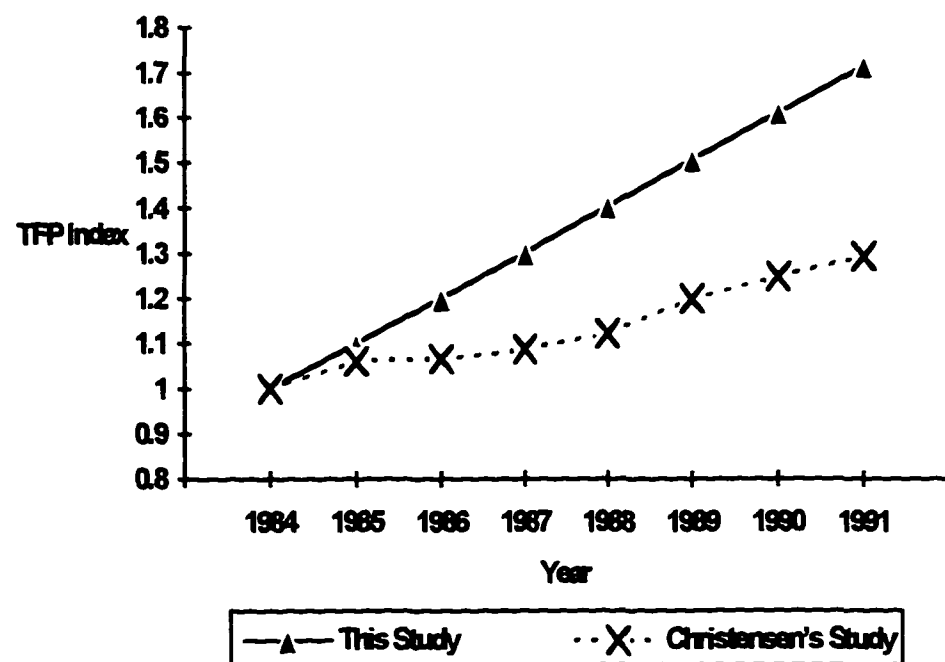
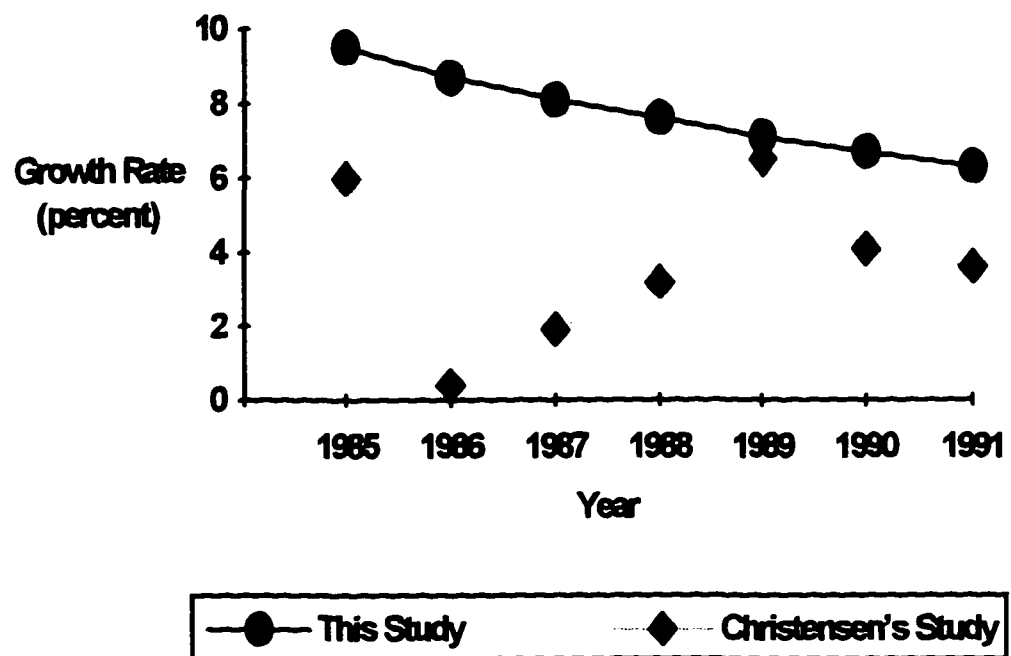
Figure 7-1: TFP INDICES COMPARED

Figure 7-2: GROWTH RATES OF TFP INDICES COMPARED

level. Notice that the coefficients on the time and time squared variables are both negative and significant. This means that costs are declining over time but these decreases in costs diminish over time. The coefficients on the price variables are all positive and significant. These coefficients have the “expected signs.” I tested the hypotheses for homogeneity by running an F test – the F value was highly significant, thus rejecting the homogeneity property.

Many authors have rejected the homogeneity property in different studies; e.g. Evans and Heckman (1984) note that “[r]ejection of homogeneity...may indicate that the translog cost function is a poor approximation to the true cost function, that the cost function is misspecified in some other basic way, or that firms do not behave as assumed by producer theory.” (Page 263). They do not attempt to resolve these issues and restrict their cost function estimates to satisfy the homogeneity property. Other authors who have rejected the homogeneity property include Gabel and Kennet (1991) and Gollop and Roberts (1981). Since the aim of this dissertation is to compare the TFP indices and growth rates with those calculated by Christensen, I too have not attempted to exhaustively deal with the issue of the rejection of the homogeneity property.³⁸

³⁸ I have, however, “imposed” the homogeneity restrictions to see how imposition of the restrictions (which many authors have done) would change the results. This is discussed below.

Using equations (7.5) and (7.6), I computed the TFP indices for each of the years 1984 - 91, using the parameter estimates in Table 7-1. I then found the growth rate for these TFP indices and computed the average TFP growth rate for the entire time period 1984 - 91. Table 7-2 shows the results. Column 2 shows the TFP indices for each year. Column 3 shows calculations using 1984 as a "base" value (indexed at 1.00). Column 4 shows the growth rates for each of these indices. The average growth rate is 7.7%. Table 7-3 compares Christensen's results with mine. Christensen computed a TFP growth rate of 3.7% for the same time period. Figure 7-1 plots the TFP indices computed in this study versus those calculated by Christensen. Notice that the TFP indices that I have calculated are all higher than Christensen's. This result is not surprising, given the argument presented in Section 1.1 that Christensen's aggregation of the output and input price indices leads to an understatement of the TFP.

Note also that the TFP index as calculated in this study has a smoother pattern than that calculated by Christensen. This might stem from the point addressed in Section 7.2 about this method having a fixed technology set as opposed to Christensen's method. With varying amounts of capital, productivity in another factor might be subject to more variation than if the technology were held fixed. Let us take a simple example. Suppose productivity is measured by spreadsheet output as generated by a person

working on a computer. If the person is started off with an IBM XT, and then graduates to a 386 machine, a 486 machine and then to a Pentium, the change in that person's productivity might be subject to significant variation. If, on the other hand, the person is started off with a Pentium, the productivity change might be a lot smoother and flatter.³⁹ This might explain the smoother pattern in the TFP index suggested by this study. Figure 7-2 is a comparison of the growth rates.

The effects of technological change and overall returns to scale on the TFP index were separated for each of the years. Technological change was computed using equation (7.5) and the overall returns to scale measure was calculated using the inverse of the term given in equation (7.6). The results are shown in Table 7-4. Notice that the average returns to scale measure is 1.283. This implies that, holding input prices constant, a 10% rise in overall output would increase costs by only 7.8%. This indicates economies of scale for the local exchange carrier and not constant returns to scale. See Section 6.1 for a discussion of this issue. Thus, as stated before, Christensen's implicit assumption of constant returns to scale casts further doubt on his TFP estimates, in addition to the aggregation problems associated with the indices.

Notice that the returns to scale measure has a constant growth rate, while the growth rates for technological change (Table 7-4) and total factor

³⁹ Credit for this example goes to Dr. Keith A. Heyen.

productivity (Table 7-2) are monotonically decreasing. The constant growth rate in returns to scale might result from the use of the translog cost function and the evaluation of the estimates at the mean values. Since the parameters of the cost function are not varied over time, the growth rate of the returns to scale measure is a function of these same parameters and the time variable. The monotonically decreasing growth rates for the TFP indices could be due to the fact that since this dissertation takes into account only the “relevant” outputs, the TFP index does not capture “technological change” as embodied by the use of inputs to produce other “new” outputs in the telecommunications sector that were not yet marketed and hence, as mentioned in Section 1.1, should not be considered for the calculation of the TFP index. This is not a problem, however, as this study is measuring the TFP index for only those traditional services that are relevant to the price cap formula (see Section 1.1). Since Christensen is lumping all outputs and inputs into single indices, this might account for the greater variation in the growth rates that he calculates. It is to be noted, though, that the TFP indices calculated in this study are increasing over time, though at a decreasing rate of growth.

Table 7-4: SEPARATION OF TECHNOLOGICAL CHANGE AND RETURNS TO SCALE

Year	(1) Technological Change	(2) RTS	(3) Growth Rate of Tech. Change	(4) Growth Rate of RTS	(5) TFP Growth Rate (3) + (4)
1984	0.059	1.265			
1985	0.065	1.270	9.1	0.4	9.5
1986	0.070	1.275	8.3	0.4	8.7
1987	0.076	1.280	7.7	0.4	8.1
1988	0.082	1.286	7.1	0.4	7.6
1989	0.087	1.291	6.7	0.4	7.1
1990	0.093	1.296	6.3	0.4	6.7
1991	0.099	1.302	5.9	0.4	6.3
Average	0.079	1.283	7.3	0.4	7.7

Note: Some numbers might not add up due to rounding

Table 7-5: TRANSLOG ESTIMATES WITH ACCESS LINES NOT TREATED AS AN OUTPUT

Variable	Estimate	S.E.	t-value	p-value(2 tail)
INTERCEP	0.32525	0.004935	65.907	0.0001
EXCH	-0.18005	0.011724	-15.358	0.0001
TOLL	-0.20096	0.011724	-17.142	0.0001
LCPL	0.57833	0.011269	51.322	0.0001
TLPL	0.57941	0.011327	51.155	0.0001
PL	0.44295	0.033360	13.278	0.0001
PK	0.38860	0.023824	16.311	0.0001
PM	0.15736	0.033426	4.708	0.0001
AREA	0.20026	0.001586	126.275	0.0001
TIME	-0.06033	0.002669	-22.602	0.0001
EXCHSQ	-0.60942	0.051619	-11.806	0.0001
TOLLSQ	-0.60267	0.051619	-11.675	0.0001
LCPLSQ	-0.08585	0.041663	-2.061	0.0393
TLPLSQ	-0.28008	0.043454	-6.445	0.0001
PLSQ	0.08192	0.108791	0.753	0.4515
PKSQ	-0.59484	0.082495	-7.211	0.0001
PMSQ	-0.15070	0.109827	-1.372	0.1700
AREASQ	-0.01323	0.000665	-19.902	0.0001
TIMESQ	-0.00549	0.000716	-7.672	0.0001
EXCHTOLL	-0.00865	0.049179	-0.176	0.8603
EXCHLCPL	0.29473	0.025517	11.550	0.0001
EXCHTLPL	0.36510	0.025800	14.151	0.0001
TOLLLCPL	0.28910	0.025517	11.330	0.0001
TOLLTLPL	0.35987	0.025800	13.948	0.0001
LCPLTLPL	-0.44814	0.039179	-11.438	0.0001
PLPK	0.34404	0.103213	3.333	0.0009
PLPM	0.02338	0.186347	0.125	0.9002
PKPM	0.35355	0.106033	3.334	0.0009
PLEXCH	0.00172	0.046586	0.037	0.9705
PLTOLL	-0.00227	0.046586	-0.049	0.9611
PLLCPL	0.02203	0.044209	0.498	0.6182
PLTLPL	-0.02210	0.044671	-0.495	0.6209
PKEXCH	0.00119	0.038980	0.031	0.9756
PKTOLL	0.01961	0.038980	0.503	0.6149
PKLCPL	-0.11763	0.037058	-3.174	0.0015
PKTLPL	0.09428	0.037447	2.518	0.0118
PMEXCH	0.00636	0.047012	0.135	0.8924
PMTOLL	0.00337	0.047012	0.072	0.9429
PMLCPL	0.00436	0.044617	0.098	0.9222

Variable	Estimate	S.E.	t-value	p-value(2 tail)
PMTLPL	-0.01259	0.045066	-0.279	0.7799
PLAREA	-0.00402	0.005736	-0.701	0.4834
PKAREA	-0.00846	0.004800	-1.762	0.0781
PMAREA	0.00062	0.005789	0.107	0.9152
PLTIME	0.00659	0.008783	0.750	0.4533
PKTIME	-0.02460	0.006270	-3.924	0.0001
PMTIME	-0.00600	0.008796	-0.683	0.4949
EXCHTIME	0.00360	0.002916	1.233	0.2176
TOLLTIME	0.00359	0.002916	1.231	0.2183
LCPLTIME	-0.01045	0.002781	-3.757	0.0002
TLPLTIME	0.00013	0.002798	0.047	0.9623
EXCHAREA	-0.18251	0.003443	-53.009	0.0001
TOLLAREA	-0.17687	0.003443	-51.370	0.0001
LCPLAREA	0.15267	0.003450	44.253	0.0001
TLPLAREA	0.14985	0.003431	43.670	0.0001
AREATIME	0.00421	0.000360	11.699	0.0001

R-squared = 0.9834

Adjusted R-squared = 0.9834

Table 7-6: TFP RESULTS WITH ACCESS LINES NOT TREATED AS AN OUTPUT

Year	TFP	TFP Index	Growth Rate
1984	0.0787	1.000	
1985	0.085	1.095	9.1
1986	0.093	1.192	8.4
1987	0.100	1.289	7.8
1988	0.108	1.386	7.3
1989	0.115	1.485	6.9
1990	0.123	1.584	6.5
1991	0.131	1.685	6.1
Average			7.4

**Table 7-7: TFP RESULTS WITH HOMOGENEITY RESTRICTIONS
IMPOSED**

Year	TFP	TFP Index	Growth Rate
1984	0.076	1.000	
1985	0.084	1.105	10.0
1986	0.093	1.211	9.1
1987	0.101	1.317	8.4
1988	0.109	1.425	7.8
1989	0.117	1.533	7.3
1990	0.125	1.642	6.9
1991	0.134	1.753	6.5
Average			8.0

**Table 7-8: TFP RESULTS WITH NO ACCESS LINES AND WITH
HOMOGENEITY RESTRICTIONS IMPOSED**

Year	TFP	TFP Index	Growth rate
1984	0.079	1.000	
1985	0.087	1.103	9.8
1986	0.095	1.207	9.0
1987	0.103	1.312	8.3
1988	0.112	1.418	7.8
1989	0.120	1.525	7.3
1990	0.129	1.632	6.8
1991	0.137	1.741	6.4
Average			7.9

Gabel and Kennet (1991) note that debates between regulators and telephone company economists arise over the treatment of access lines as an output. Utility economists believe that access to the telephone network should be considered a separate output while Gabel and Kennet feel that it should not – after all, why would consumers want just “access” to the network without then using the network to place and receive calls themselves? Would consumers value access as a separate output? In order to compare, the translog was estimated with access lines not treated as an output. Table 7-5 shows the translog estimates for this case. Table 7-6 shows the TFP indices for the time period considered. The average TFP growth rate is 7.4%, which is again higher than Christensen’s rate of 3.7%.⁴⁰

Numerous authors have imposed homogeneity restrictions when estimating the translog cost function, including Shim and Ying (1992) and Evans and Heckman (1983). See Kennet, Heyen and Gabel (1995) for a detailed discussion of this issue. I wanted to see how imposition of the restrictions would change my TFP results. Table 7-7 shows the relevant growth rate calculations. In this case access lines were added back as an output in the calculations. Notice that the average growth rate of TFP has increased to

⁴⁰ This average growth rate of 7.4% is not (statistically) significantly different from the average rate of 7.7% calculated earlier i.e. when access lines were included as an output.

8.0%, which is even higher, although again not statistically significantly different than the 7.7% estimate derived without the restrictions imposed.

Access lines were removed again and the homogeneity restrictions were imposed at the same time. Table 7-8 shows these results. In this case, the average growth rate of the TFP index is 7.9%.

Summarizing the above results we see that, when the homogeneity restrictions are not imposed, the average TFP growth rate lies between 7.4% and 7.7% depending on whether access lines are excluded or included, respectively, as an output. Further, when the homogeneity restrictions are imposed the corresponding numbers are 7.9% and 8.0%, respectively. So even the lowest TFP average growth rate of 7.4%, depending on which assumptions one wants to make, is far higher than Christensen's growth rate of 3.7%.

7.3 Calculation of the X-Factor for 1984 - 1991

This section draws on the FCC's (1995a) *First Report and Order*. In Appendix F, the FCC discusses the issue of total factor productivity and input prices: "All parties agree that, in competitive markets, changes in output prices reflect changes in input prices as well as changes in TFP... [In order to] replicate the results of a competitive market, a "productivity offset" to inflation (i.e., an X-Factor) must reflect both TFP changes and input price changes."

(FCC, 1995a, Appendix F, page 1). It presents a formula for LEC price changes, under perfect competition, as:

$$\%P^{LEC} = \%P^{US} - [(\%TFP^{LEC} - \%TFP^{US}) - (\%W^{LEC} - \%W^{US})] \quad (7.7)$$

where

$\%P^{LEC}$ is percentage change in LEC output prices

$\%P^{US}$ is percentage change in U.S. output prices

(inflation)

$\%TFP^{LEC}$ is percentage change in TFP for the LEC

industry

$\%TFP^{US}$ is percentage change in TFP for the US

economy

$\%W^{LEC}$ is percentage change in input prices for the

LEC industry

$\%W^{US}$ is percentage change in input prices for the U.S.

economy

The X-Factor is the term in the square brackets i.e.

$$X = (\%TFP^{LEC} - \%TFP^{US}) - (\%W^{LEC} - \%W^{US}) \quad (7.8)$$

The FCC mentions that studies by Christensen, the National Economic Research Associates (NERA) and the United States Telephone Association (USTA) assert that the input price differential term $\%W^{LEC} - \%W^{US}$ is not

significantly different from zero, and hence that the X-Factor should only include the TFP differential. AT&T and Ad Hoc studies presented to the FCC show that elimination of the input price differential is not justified. The FCC "...believe[s] that inclusion of the input price differential...is essential to the proper calculation of the X-Factor." (FCC, 1995a, Appendix F, page 10). Furthermore, it (the FCC) finds, based on data from Christensen and the Bureau of Labor Statistics, an X-Factor of at least 4.8% for the period 1984 - 90, excluding the Consumer Productivity Dividend (CPD).

Christensen (1993) asserts that "during the post-divestiture period Indiana Bell achieved average TFP growth of 3.7% per year, and the U.S. economy achieved TFP growth of .9% per year. The differential is 2.8%, which would provide the basis for a 2.8% offset to the GNP Price Index in a rate stability formula." This means that Christensen, in this 1993 study, feels that the X-Factor should be calculated as 2.8%.

Using the FCC (1995a) worksheet on page 15 of Appendix F, I calculated the average X-Factor implied by my study, for the period 1984 - 91. I have used the FCC data on TFP growth in the U.S. economy and the input price differential. Even though the FCC has used the TFP growth for the LEC industry as a whole, I have used Indiana Bell's TFP indices that I calculated in this study. Whether to include firm-specific TFP indices or industry indices in the price cap formula is another issue altogether. I feel that the standard should

be set by the “efficient” firm – the industry leader – in determining allowed price changes. In doing this, other firms will have an incentive to increase their productivity and thus reap additional benefits. Consider the airline industry. Prices are determined by the actions of the efficient firms and not by the actions of the inefficient ones. The relevant productivity of the industry should not be the industry average but the productivity of the price leader. Similarly, in the case of the local exchange carriers, the leader’s TFP should be the relevant standard. The results that I have obtained would either be the upper limit for the X-Factor if Indiana Bell is indeed the leader, or would be an underestimate if another LEC is the leader -- in this case, a higher X-Factor would result.

Table 7-9 shows the calculations for the years 1984 - 91. The X-Factor for this period works out to 10.1 (not including the CPD), **much higher** than Christensen’s (1993) figure of 2.8%. Furthermore, Christensen used a 0.9% TFP growth rate for the U.S. economy, while I used a 0.1% TFP growth rate, as shown in the FCC worksheets. Even if the 0.9% figure were used, I still get an X-Factor of 9.3.

Table 7-9: X-FACTOR USING FCC (1995a) WORKSHEET

Year	LEC TFP Growth	US TFP Growth	US Input - Telecom Input	LEC TFP - US TFP	X Factor
1984					
1985	9.5	0.5	3.87	9.0	12.9
1986	8.7	1	2.49	7.7	10.2
1987	8.1	0.1	1.49	8.0	9.5
1988	7.6	0.6	7.81	7.0	14.8
1989	7.1	-0.3	7.88	7.4	15.3
1990	6.7	-0.3	-7.59	7.0	-0.6
1991	6.3	-1.1	1.55	7.4	9.0
Average	7.7	0.1	2.5	7.6	10.1

7.4 Summary and Conclusions

In this dissertation, I calculated TFP indices for the years 1984 - 91, using similar output growth rates as Christensen (1993) and using the same input prices indices. I first simulated the costs incurred by Indiana Bell over these years using a cost-optimization model, LECOM. I then estimated the parameters of a translog cost function and used these parameters to compute the TFP indices for 1984 - 91. The average TFP growth rate turned out to be between 7.4 and 8.0%, depending on what assumptions were used, i.e. whether or not to treat access lines as an output and whether or not to impose homogeneity restrictions. These average growth rates are significantly higher than the 3.7% average TFP growth rate computed by Christensen.

The X-Factor was calculated for the same time period using figures from the FCC (1995a) worksheet. Using the FCC estimate of 0.1% for the US economy's TFP growth, the X-Factor was 10.1, excluding a Consumer Productivity Dividend. Using the rate of 0.9% that Christensen used, the X-Factor was 9.3, excluding the CPD.

These results seem to indicate that traditional TFP studies tend to underestimate the true productivity growth rate of the local exchange carrier. The use of LECOM will provide the FCC with an independent quantitative tool

by which it can might be able to measure the TFP for the carrier. This in turn would lead to just and reasonable rates for consumers.

It is to be noted that both Christensen and I are trying to calculate an index (namely the TFP index) and both have certain limitations. The reader must realize that this is a challenging task with the types of data that are available. The costs of providing certain outputs for a Local Exchange Carrier depend on a variety of inputs, most notably capital (since telecommunications is such a capital-intensive industry). Most TFP studies use historical balance sheet data, and then adjust these values to reflect different vintages of capital, to arrive at the data they use for the capital input. The limitation here is that these balance sheets do not attempt to separate replacement of the existing capital stock from new capital that is used for technological innovation. This study's limitation is that it uses LECOM as a data-generating process that keeps technology fixed. Alternative TFP estimates might result if these issues were treated differently.

The author realizes that the results presented in this study are based on the use of the translog formulation of the cost function (which is, however, considered one of the standard functional forms used in the literature). Use of another functional form might change the results. This will be incorporated in future research. This study will also be extended to include an experiment to construct an aggregate output index from the data generated by LECOM. This

aggregate index will then be used to compute a TFP index in order to directly compare the estimates derived by Christensen using his aggregate indexes with those computed using aggregate indexes derived from LECOM. This might help confirm the direction of the bias of Christensen's TFP calculations with direct comparison of the aggregate-based measures.

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