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THE STRUCTURE OF COST AND DEMAND IN THE U. S. TELECOMMUNICATIONS INDUSTRY

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A Dissertation APPROVED FOR THE
DEPARTMENT OF ECONOMICS

BY

Dedicated to My Parents

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ABSTRACT

This dissertation provides an analysis of cost and demand structures in the U.S. telecommunications industry from 1960-1999. The research is primarily concerned with the effects of deregulation, competition and technology on the structures of cost and demand on the cost and demand structures. Short and long run industry models are estimated with non-linear three-state least squares regression techniques. The analysis provides information about telecommunications economies of scale, capital investment, and cross subsidization. Evidence indicates strong economies of scale in the last fifteen years of the sample. These scale economies may be attributable to an unprecedented increase in general R&D investment, significant investments in fiber optic technology and recent mergers and acquisitions among telecommunications companies. Empirical results also indicate efficiency gains from deregulation and competition in toll and local markets. Based upon these findings, several policy recommendations are offered. In general, these proposals are designed to increase competition, speed technology deployment, promote investment and prevent inefficient mergers in the U. S. telecommunications industry.

INTRODUCTION

Recurring events in the history of regulation of the U. S. telecommunications industry generally center on regulators' attempts to reconcile regulatory goals with the changing structure of the industry. Goals that were once important may not be relevant today, and methods that were successful in the past may not be effective in the present. Yet, the interpretation of these recurring events is often complicated by time lags between policy implementation and market changes. Regulatory agencies often find it necessary to re-examine their expected roles and the necessary scope of their oversight. They are often placed under pressure from the public and the industry to either ease or tighten regulation.

Initially, the main goals of telecommunication regulation were simple: (1) protection against monopoly power and price exploitation and (2) promotion of universal service and affordability of basic telephone service. The telecommunications market was dominated initially by the Bell companies. The American Bell Telephone Company, organized in 1880, provided local exchange service and American Telephone and Telegraph (AT&T), organized in 1885, provided nation-wide long distance service. In 1894, with the expiration of Alexander Bell's phone patent, numerous independent telephone companies were established providing services to areas not served by the Bell companies. Between 1894 and

1904, over six thousand independent telephone companies began offering service across the United States. [1]

Federal regulation of the U. S. telecommunications industry was authorized by the Mann-Elkins Act of 1910. This legislation gave authority to regulate telephone service to the Interstate Commerce Commission. It was not until the 1934 creation of the Federal Communications Commission (FCC), however, that the federal government took an active role in telecommunications regulation. At that time, the FCC was assigned interstate jurisdiction while state governments were granted jurisdiction over local and intrastate toll rates. Since the creation of the FCC, telecommunications markets have changed significantly. Technological and market structure changes have lead to continuing changes in the goals, scope, and nature of regulation. The essential goals of price protection and universal service have not changed, but more regulatory objectives have been added. Today, regulators are also concerned with promoting technological innovation, encouraging efficient production, ensuring quality of service and facilitating access to advanced telecommunications services in rural and remote areas.

As far as the regulatory environment, the first major event occurred in 1949, when an antitrust lawsuit was filed to separate Western Electric, AT&T's equipment manufacturing affiliate, from AT&T. The intent of the lawsuit was to allow for competition in the manufacturing of telephone equipment. The lawsuit was resolved

[1] AT&T's website at www.att.com.

in 1956 with a consent decree, which required AT&T to engage only in regulated common carrier services. In addition, Western Union, of which AT&T owned shares, agreed to engage only in equipment manufacturing for AT&T's regulated services.

Until the late 1960s, telecommunications regulators generally viewed the telephone industry as a natural monopoly[2]. The principle, initially promoted by then AT&T president Theodore Vail in 1907, was that the telephone industry by the nature of its technology would operate most efficiently as a monopoly providing universal service. The federal government formally accepted this principle for the first time in a 1913 agreement known as the Kingsbury Commitment. Accordingly, rate-of-return regulation was thought to be the appropriate approach for maintaining the firm's viability and protecting the public interest. Rate-of-return regulation guaranteed AT&T and the Bell System an opportunity to earn a "fair" return on capital investment. In addition, the firms were protected from competition by exclusive franchises in their respective service territories. In return, the firms agreed to maintain quality of service standards and provide universal service.

This regulatory arrangement changed in 1959 with the authorization of interexchange competition. At that time, the FCC issued its "Above 890 Decision" (referring to microwave frequencies above 890 megacycles), which authorized interexchange competition by approving the development of private microwave

[2] For example, the FCC's remarks in Jurisdictional Separations Reform, FCC-CC Docket No. 80-286, released in Oct. 7, 1997, "(T)he separations process that was ultimately codified into the Part 36 rules evolved during a time (1969) when common carrier regulation presumed that intrastate and interstate telecommunications services must be provided through a regulated monopoly." Time reference added.

systems. Microwave technology was beginning to emerge as an alternative technology to the traditional copper wire provision of telephone service. Microwave Communications, Inc. (MCI) commercialized microwave technology for the first time in 1963. In 1969, the FCC approved MCI's application to provide private line service between Chicago and St. Louis. Thus, the first competitive long distance company appeared.

With the advent of microwave technology was invented, telecommunications regulators were faced to deal with a new type of interexchange provider. Federal regulators had to reconsider AT&T's long distance rates, which were set high enough to subsidize local exchange rates. In addition,, low rates for local exchange service were challenged by rising costs occasioned by Bell companies heavy investment in new computerized switches in the mid 1960s[3]. Regulators, at the federal and state levels, had to address these technical and structural changes in order to preserve universal service and affordable telephone rates.

One regulatory response was to change accounting procedures. A system of accounting "separations" was implemented in an attempt to allocate the costs of local and interexchange services. In 1969, Part 36 of the Federal Communications Commission's rules set forth formal separations procedures adopted by

[3] Total operating costs for local exchange companies rose from an annual average rate of 6% in the early 1960s to almost 9% in the mid to late 1960s, culminating with an average annual rate increase of 14% by the end of the decade. Source: FCC SCCC, 2000 Edition.

approximately 700 carriers[4]. The separation process developed a method of allocating costs to local service, which could be reimbursed through interstate rates. At the state level, a system of subsidies was implemented whereby business rates and intrastate toll rates were set above cost in order to subsidize local rates.

Another regulatory response to technical and structural changes was the authorization of resale of AT&T's interstate services. This began in 1976, when the FCC ruled that AT&T's prohibition to resell its private line services was unjust and discriminatory[5]. In 1981, the FCC permitted the resale of AT&T's message telecommunications services and wide area telecommunications services[6]. The FCC believed that resale of these services would eliminate inefficient duplication of network facilities, bring prices closer to cost, and promote competition. After holding a virtual monopoly for almost a century, AT&T had to finally contend with "sharing" the market with other carriers.

In 1982, a consent decree, ordered by Judge Harold H. Greene, called for the divestiture of AT&T from its twenty-two Bell operating companies, thereby

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[4] Since 1930, costs and revenues associated with facilities used to provide both intrastate and interstate telecommunications services have been allocated between interstate and intrastate jurisdictions. Cooperative efforts undertaken by the industry, state regulatory agencies, and the FCC beginning in 1941, were incorporated into a Separations Manual in 1947. Source: Jurisdictional Separations Reform, FCC-CC Docket No. 80-286, released in Oct. 7, 1997.

[5] Regulatory Policies Concerning Resale and Shared Use of Common Carrier Service and Facilities, FCC 2nd 262 (1976).

[6] American Telephone and Telegraph Company Revisions to Tariff FCC 259, Wide Area Telecommunications Service; and Regulatory Policies Concerning Resale and Shared Use of Common Carrier Domestic Public Switched Network Services, 86 FCC 2nd 820 (1981).

restricting its services to long distance only. The Bell operating companies became seven Regional Bell Operating Companies (RBOCs) offering only local exchange and intrastate intraLATA (or Local Access Transport Areas) toll services. The RBOCs are Ameritech, Bell Atlantic, Bell South, NYNEX, Pacific Telesis, Southwestern Bell, and U. S. West. In addition, the consent decree allowed AT&T to retain its research laboratories, Bell Labs, and to retain equipment manufacturing as a line of business. In addition, the MFJ designated 192 Local Access Transport Areas (LATAs) across the country to delineate local and toll boundaries. The RBOCs were also required to provide equal access to their local networks to all long distance companies.

New regulatory experiments began in the late 1980s. First the FCC[7] and then some states experimented with "alternative regulation." Alternative regulation generally refers to regulatory policies other than rate-of-return regulation. Alternative regulatory approaches evolved out of necessity. State and federal regulators were faced with structural and technological changes that could not be ignored. The introduction of competition in the toll market threatened previously protected monopolies. Resale competition in the intraLATA and interLATA toll markets also created new market realities. Technological advancement altered the industry's cost structure, created new types of services, and created new relationships among established and new telecommunications service providers.

[7] Price cap regulation was first adopted by the FCC in 1989.

The next significant piece of regulatory legislation was the Federal Telecommunications Act (FTA) of 1996. It called for sweeping changes which superseded the AT&T divestiture's consent decree. The Act covered telecommunications services, broadcast services, and cable services among others. Its main telecommunications provisions are: allowing local exchange competition; lifting prior restrictions on the RBOCs to enter toll markets provided they first meet a checklist of conditions[8]; providing for infrastructure sharing; creating incentives for deployment of advanced telecommunications; creating new provisions for universal service; enacting new measures to prevent unfair billing practices; and establishing a telecommunications development fund.

The Federal Telecommunications Act of 1996 was, for the most part, received with much hope and enthusiasm. It has been several years since its passage. The regulatory environment has certainly changed, but the debate continues as to the success or failure of this act. The debate, in some respects, is not new. Regulators and analysts alike have long been preoccupied with the effects of regulation on industries, as well the effects of *industries* on regulation. The novelty of the question at every historical turn is how can the concept of regulation adapt to changes in industries? The answer lies not only in lessons learned from the present, but also in lessons learned from the past.

[8] The FTA's checklist includes: interconnection with facilities-based competitors, unbundled access to all network elements, access to poles and rights-of-way, unbundled price for loops, trunks and switching, local number portability, and wholesale pricing for resellers. Unbundled network elements (or UNEs) refer to (1) loops, including loops used to provide high-capacity and advanced telecommunications services; (2) network interface devices; (3) local circuit switching (except for larger customers in major urban markets); (4) dedicated and shared transport; (5) signaling and call-related databases; and, (6) operations support systems.

The main objective of this research is to examine the changing structure of the U. S. telecommunications industry over the last forty years. The purpose of the research is to gain insights into the relationships between economic events and regulatory policies. Hopefully, these insights will provide a better understanding of the telecommunications industry and help shape future telecommunications policies. New analytical tools and modified performance measures are developed to address new issues and unfamiliar phenomena. Chapter One consists of a literature review. Chapter Two discusses theoretical issues and describes the theoretical model. Chapter Three describes the data and its sources. Chapter Four describes the empirical model and presents estimation results. Chapter Five describes alternative models and specifications. Chapter Six contains general conclusions and policy recommendations.

Literature Review

The main concern of early telecommunications studies in the 1960s was the concept of a natural monopoly. The concept simply means that certain industries, usually those with a high capital intensity structure, are predisposed to the realization of economies of scale at very large levels of operation. Hence, the market will typically accommodate only a single large producer. Related to the concept of economies of scale is the notion of returns to scale. If one assumes that all inputs are increased in the same proportion, say by a 100%, holding technology constant, and as a result output increased by, say, a 120%, then one would say that there are increasing returns to scale. Alternatively, if output increased by, say, 80%, then returns to scale are decreasing (constant if output increases by exactly 100%). The presence of economies of scale could enforce the presence of a natural monopoly. The focus of most empirical work in telecommunications was therefore on verifying or negating the presence of natural monopolies in the telecommunications industry.

Interest in natural monopolies in the 1970's continued, as most of the studies then were concerned with the presence and measurement of economies of scale. Studies by Fuss and Waverman (1977), Denny et al (1979), and Smith and Corbo (1979) provided evidence of economies of scale for the U. S. and Canadian Bell systems. Recent studies on the same question, however, have produced mixed results. Christensen et al (1983) find evidence of economies of scale of 1.3 to 1.7 for the Bell companies. Evans & Heckman (1983) apply a subadditivity test for the Bell System and find no evidence that the Bell system is a natural monopoly. Charnes et al (1988) reach opposite conclusions to the Evans & Heckman study using goal programming restrained regression as an approach. Roller (1990) uses a generalized CES-quadratic cost function and finds evidence of pre-divestiture natural monopoly for the Bell companies. Shin & Ying (1992) argue that the disparities on the economies of scale issue lies in the choice of data. They use panel data, rather than time series, and find no evidence of pre-divestiture natural monopoly. Zhou (1996) finds that failing to account for firm heterogeneity understates scale economies of LECs. It is evident that empirical measurements of economies of scale are quite sensitive to the tools of research, specification issues and data measurement assumptions.

Cost and Production Studies

My research focuses on the cost and demand structures of the U. S. telecommunications industry. Of particular interest are the effects of technological developments and regulatory changes on capital and R&D investment, competition, and economies of scale. A recent study by Sung and Gort (2000) examines economies of scale and natural monopoly in the local telephone industry for the years 1951-1991. They estimate a flexible total cost function with variables reflecting the quality of capital and of labor. They find that economies of scale are a decreasing function of firm size. Their evidence shows that local exchange companies earning a maximum of $150 million in revenues have returns to scale of 1.10, whereas companies earning a maximum of $8 billion have diseconomies of scale averaging 0.964. They attribute the difference to the fact that sources of scale effects may be specific to the firm rather than to the product. They argue that larger firms may have high labor and network monitoring costs, while smaller firms may have an advantage in labor specialization and in learning by doing.

Other recent studies have examined the effects of various technological changes on the structure of the telecommunications industry. Zhou (1996) examines the effects of modern switching and fiber optical technologies on the cost structures of local exchange carriers. He emphasizes the role of firm heterogeneity as a key determinant of cost structure. He finds, first of all, that during the sample period (1988-1994) average costs have declined. However, he finds that the decreases in average costs have resulted primarily from decreases in factor prices and only marginally from improvements in technology. He finds that regulatory variations produce mixed results.

Zhou further finds that a 10% increase in electronic switching reduces total cost by only 1.2%. Fiber deployment, on the other hand, causes a reduction of 2.3% in total cost. He notes that the measured cost effects of advanced technology in telecommunications are generally small. He hypothesizes that advanced technologies may be more product-oriented than process-oriented which may put upward pressure on production costs rather than lowering them. Zhou's measure of fiber deployment is calculated as the percentage of deployed fiber cable *in total cables*. His measure reflects the intensity of fiber deployment for a given number of cables, while my measure reflects the overall national level of fiber cable deployment. Given Zhou's limited sample, and the fact that the intensity of fiber for a given number of cables is considerably high, it follows that the cost saving effects would be higher. The effect of nation-wide fiber deployment measured by the number of fiber miles per year may not be as pronounced considering the geographical scope over which fiber deployment is spread.

Nadiri and Nandi (1999), in a related paper to their 1997 study, provide empirical results of the effect of direct technical change in the telecommunications industry. They find that technical change is a major contributor to total factor productivity (TFP). In absolute terms, it accounts for 1.8% to 2.5% of annual TFP growth. Nadiri and Nandi find that, since 1974, the contribution of non-marginal cost pricing and of scale growth have gradually increased while the contribution of technical change has decreased. The authors posit two reasons for the decline in the effect of technical change: one is the transitional effects following divestiture, the other is possible data measurement problems. They argue that such problems could be addressed with better and more recent data, which this dissertation will attempt to accomplish.

Most telecommunications production studies assume disembodied technical change, in which technology is independent of the vintage of the factors of production. Sung (1998), however, considers two separate measures of disembodied and embodied technical change in the cost function. This is achieved by incorporating two quality indexes for labor and capital, while maintaining a time variable. He considers a set of pooled data of eight U. S. local exchange companies for the period 1951-1991. He finds that when a competition index is inserted in place of the time variable to control for disembodied technical change, the productivity growth due to improvements in labor and capital quality indexes explain more than half of the rate of technical change. Thus, if LECs reduce their investment in network technology, or if they decrease their net capital formation, they may experience a sharp drop in their productivity growth.

Regarding the effects of regulation on the cost structure, productivity and efficiency of the telecommunications industry, there are mixed empirical results. Chappell (1998) examines the effects of regulation on the diffusion of technological innovations in the local telephone industry by measuring the timing of investment and the replacement date of investment. She finds that differences in state regulatory procedures, such as depreciation practices, affect the rate of first adoption of digital central office equipment, but not so for fiber optics. She also presents evidence that more liberal depreciation policies and higher earned rates of return (ROR) on investment result in more rapid conversion of telephone network to digital office technology.

Lee (1997) explores the impact of price cap regulation (PCR) relative to ROR regulation on telecommunications infrastructure deployment. Specifically, he tests the hypothesis of strategic behavior in the choices of risky and non-recoverable investments under binding and non-binding regulatory policies. He finds that PCR has a significant and positive relationship with the deployment of fiber and digital switches (which he considers non-recoverable technologies[1]), and a negative but insignificant one with ISDN (which he considers risky technology). He reasons that since investment in new technologies entails substantial non-recoverable costs, the firm will invest more than the optimal level in order to establish barriers to entry. He adds that a non-binding price cap regulation, due to a healthy demand and a declining cost due to technological innovations, will essentially allow the firm to act as an unregulated monopolist. On the other hand, if a new investment is not guaranteed to generate sufficient demand[2], the firm will be more reluctant to make such a risky investment under non-binding PCR than under ROR regulation (where a guaranteed rate of return exists).

Krouse, et al (1997) examine the effects of divestiture and regulatory reform on the efficiency of the Bell operating companies (BOCs). The study finds that, as of 1993, there have been significant efficiencies, totaling over 25% of the incurred costs. The study finds that divestiture has labor-saving and capital-using effects on cost, while regulatory reform has the opposite effect. The authors conclude that regulation reform effects are somewhat larger than the divestiture effects.

Majumdar and Chang (1996) examine the dynamic scale efficiency patterns of thirty-nine local exchange companies in the U. S. for six time periods ranging from the

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[1] Non-recoverable technologies are defined as those which require significant up-front investment. Such investment entails a largely irrevocable (or sunk) cost.

[2] A new investment may not guarantee sufficient demand, if the final product for which the investment is made is non-conventional, high-maintenance, or too expensive.

mid 1970's to 1990. They define scale efficiency as the ability of each company to operate as close to its most productive scale size. Computed scale efficiency scores are regressed on a set of variables capturing firm-specific and environmental factors that may influence variations in firm-level scale efficiencies. They find that over the sixteen-year period the mean scale efficiency scores have increased from 0.879 (unity is the maximum) in 1975 to 0.952 in 1990. The largest absolute increase occurs between 1981 and 1984, which, as they point out, is consistent with the fact that inside wire was no longer a BOC asset after 1984, resulting in a reduction in plant size.

Majumdar and Chang also examine environmental factors, such as competition in the toll market, price caps, and local competition (shared tenant arrangements[3]). Competition in the toll market shows positive and significant values for its respective years (1984 and 1990). Price cap regulation show a positive correlation with scale efficiencies, however it misses being significant. The authors attribute one reason to the fact that in 1990 there was relatively little state-level incentive regulation. The study also finds that the introduction of intra-LATA toll market competition and incentive regulation schemes have positively impacted firms' abilities to attain scale efficiency. However, competition in local markets have not had the expected results. The study also finds that the Bell operating companies are no different than the independent LECs in their ability to be scale efficient.

[3] Shared tenant service is the provision of a private branch exchange (PBX) usually by a landlord to multiple customers located in the same building or campus. These arrangements preceded local exchange competition and were frequently restricted by state regulation.

Oum and Zhang (1995) examine whether the introduction of competition has increased productive efficiency in the U. S. telephone industry for the period 1951 through 1990. They find that competition induces incumbents to utilize their capital inputs more efficiently, thereby reducing the allocative inefficiency associated with the Averch-Johnson effect. Oum and Zhang also find that since competition was introduced in the long distance market, the ratio of the shadow price to market price for capital has been brought closer to the equivalent ratio for labor. Results similar to Nadiri and Nandi's (1997) are found with respect to over investment in capital. Results show that over-capitalization was prevalent prior to 1977. Also, the ratio of the shadow price to the market price of capital jumped in the post 1977 period, increased over time and has increased as the competition index has increased. Overall, the study concludes that over-capitalization has been reduced as competition increased over time.

A study by Crandall and Galst (1995) on productivity growth decomposes total factor productivity (TFP) growth estimates into scale effects and efficiency gains. The study examines the performance of the productivity growth of AT&T, the BOCs, and the independent telephone companies from 1984 through 1991. Crandall and Galst find evidence that independent LECs enjoyed the greatest growth in output per unit input, followed by AT&T and trailed by the RBOCs. The reason for this disparate performance is attributed to the different output growth rates for the period. The independents had the greatest output growth despite the fact that long distance services grew more rapidly. Part of the reason is that they had a higher rate of access-line growth, but also a slower growth in revenue per line. The decomposition of the TFP growth estimates into scale effects and those attributable to efficiency gains depends on the assumed scale elasticity in telecommunications. But, as the authors point out, any simple adjustment for scale economies is likely to be misleading. The growth in telecommunications output may reflect an extension of service into new areas and new exchanges, the filling of existing exchanges with incremental customers along an existing trunk line, the growth in long-distance services, or the emergence of new services. As for the slowdown of the RBOCs, the reason is attributed to the AT&T divestiture rules, which placed restrictions on the development of certain new products by the RBOCs.

Demand Studies:

The demand for telecommunications services is unique in many respects. For one, consumption of telecommunications services consists not only of usage but also of access to the services. In addition, it exhibits externalities both positive and negative. The higher the number of subscribers to the network, the larger the marginal benefits of the service as more telephone numbers can be reached. By the same token a completed call implies the imposition by the caller of the cost of answering the call by the recipient of the call. In addition, the demand for telecommunications services is unique in that the services are so heterogeneous that almost any aggregation, though commonly applied in empirical research, is to some degree unrealistic and potentially problematic.

A common mathematical depiction of telecommunications demand equations is the double-log functional form. It is easy to estimate and it yields elasticities directly from the coefficients. The price elasticity of demand is the regression coefficient of the price variable. However, in the double-log form, the elasticity of demand is assumed to be constant, which may not be consistent with economic theory or actual practice. But unfortunately there have been no successful attempts in empirical literature to formulate telecommunications demand equations that have variable coefficients and elasticities while maintaining the double-log form

Many telecommunications demand models are linear. In the linear form function, the income elasticity and the cross-price elasticity are implicitly assumed to approach unity, which may also be inconsistent with actual practice. As economic theory suggests, the income elasticity and cross-price elasticity of demand should diminish as income and the price of a substitute increase. The changing trends of elasticities implied in the linear form may be inconsistent with economic theory or consumer behavior.

Many demand studies have been conducted for the U. S. telecommunications industry. There are several good review articles such as Taylor (1980) and Wolak (1993). Most of the studies in the 1980's focused on the effects of converting from flat-rate to measured rate service on local telephone usage and calling patterns. In the 1990's, some studies have focused on the effects of deregulation on intraLATA (e.g., Taylor and Zona) and interLATA toll demand (e.g., Crandall and Waverman). Others have focused on dominant firm pricing (e.g., Kahai et al, and Blank et al). Of interest to this research are recent U. S. demand studies that examine the effects of deregulation and competition, studies that consider the interdependence between local and toll services as well as that between demand and cost, and studies that consider varying elasticities in the structure of the demand equation.

Flannery (1996) studies the effects of relaxed regulation on intrastate telephone prices. She constructs state-level panel data sets containing prices as well as regulatory and demographic variables. She finds that allowing entry into the intraLATA market during the years 1983 and 1987-1993 results in lower intraLATA prices in all mileage bands of the Bell Operating Companies (BOCs). She finds similar results for the BOCs' business and residential rates in urban and local areas for the years 1985 and 1988-1993. And she finds that reduced regulation results in lower prices for AT&T's interLATA service for the years 1983, 1987, 1990 and 1991.

Taylor and Zona (1997) examine the state of competition in the post divestiture long distance telephone market. They assess the degree of competition and the extent to which reductions in carrier access charges lead to iower interstate prices. In essence, they consider the relationship between cost and demand for interstate services. They rely upon the Bresnahan (1989) method of estimating the degree of monopoly power in a market based upon observed evidence of the firm's pricing behavior. The relationship is expressed as follows:

$$P_t = C_t \,/\, 1 + (\theta \,/\, \varepsilon_t),$$

where P_t is the price of a good at time t; C_t is the cost of a good at time t; ε_t is the price elasticity at time t; and θ is indicator of market power. If θ is = 0, then market power is absent; but if it is > 1, then it indicates market power. Taylor and Zona found θ to equal 2.55, which far exceeds the level one would expect under competition. Although access charges are a significant portion of IXCs' costs, they do not encompass all costs of production. Therefore, caution must be exercised in interpreting that result.

Caution must also be excised with respect to the notion of variable stability. In the economics literature, the independence of an elasticity measure from the level of an explanatory variable is sometimes referred to as "stability" of that measure. But, as noted by Hackl (1996), this stability does not imply that the elasticity is constant over time. There are many theoretical reasons, as he points out, to assume non-constant elasticities, such as changes in technology, shifts in taste and preference, institutional changes and changes in business cycles. Hackl considers a varying-elasticity model for the demand for telecommunications between Sweden and Germany, the U. K. and the U. S. for 1976-1990. The short and long run price elasticities are consistent with prior empirical studies. However, he finds that recursive estimation supports theoretical assumptions of time variability of price elasticity. Two different approaches are used that avoid the assumption of constant parameters. One approach is based on a state-space model with stochastically varying parameters using a filtering technique; the other approach is the moving local fitting of the above specified constant-parameter model. The main conclusion is that the hypothesis of constancy is not realistic for any country model.

THE THEORETICAL MODEL

Theoretical Background

The regulation of the U. S. telecommunications industry has provided a favorable environment for empirical economic research of the production and demand aspects of regulated monopolies. The recurring need for action in response to changes in the structure of the industry continues to capture the attention of the public and private sectors as well as academia.

The first wave of significant econometric studies of the U. S. and Canadian telecommunications industries began in the early 1970's. Output was typically modeled as an exponential function of capital and labor (and possibly other variables). A typical Cobb-Douglas can be expressed as:

$$Q = f(K, L, M) = A\ K^{a} L^{b} M^{c},$$

where Q is output, A is technology, K is capital, L is labor, and M is materials. The coefficients a, b, and c are unknown parameters to be estimated. Their sum is the returns to scale value of this function. This can be seen if the above function is multiplied by some factor, say λ; the result is $\lambda^{r}Q$, where $r = a + b + c$. Input demand equations can be derived by first taking the derivatives of the function with respect to each of the input quantities and then, assuming profit maximization, applying an expression for the equality of input prices and the values of marginal products.

The Cobb-Douglas production function, however, restricts the elasticity of factor substitution to unity, so that the percentage change in the ratio of factors of production is always equal to the percentage change in the ratio of factor prices. Due to this restriction, efforts were made to model alternative production functions, such as the constant-elasticity-of-substitution (CES) function. The CES function has the advantage of not having an a priori unitary elasticity of substitution between factors of production. The elasticity of substitution is necessarily a constant, however. Therefore, its flexibility as an analytical tool is also limited. This limitation was overcome with the development of duality theory by Diewert (1971) and Christensen et al (1971).

Duality theory made it possible to derive a joint cost function from a production function without imposing a priori restrictions on the structure of production. Brown et al (1979) show that these restrictions, though common, can distort estimates of marginal costs and economies of scale. So, in lieu of invoking a priori restrictions, one can treat those restrictions as testable hypotheses. The development of these flexible functional forms, especially the translog cost function, played a significant role in shaping telecommunications research. The shift toward cost functions proved to be especially practical, since cost data in the telecommunications field tend to be more readily available through regulatory channels than production data. Also, an advantage of the translog function is that it contains fewer parameters than other flexible forms. It also permits economies of scale to vary with the level of outputs and factor prices. Estimates of scale economies and elasticities of substitution can be easily derived as well.

While attempts were made to make production relationships more flexible, other attempts were also made to address the relationship between the short run and the long run. Economic theory indicates that some factors of production are fixed in the short run, while all factors are assumed to be variable in the long run. Empirically, researchers have attempted to carry out this dichotomy by introducing dynamics into their econometric models. The earliest approach was a static single-equation model with an imposed lag structure, such as a Koych lag structure. A second and more recent approach acknowledges the interdependencies of factor demands and distinguishes between variable and quasi-fixed factors. A third approach includes an explicit cost-of-adjustment mechanism. The problem with the first approach is that it assumes an exogenous and constant speed of adjustment. For the purpose of my research, this approach is too restrictive, since it does not allow for the opportunity to explore the inter-relationships between variable and fixed inputs, nor does it distinguish clearly between short run and long run elasticities.

The second approach, referred to by Berndt et al (1981) as second generation dynamic models, is more flexible and much more rewarding. One form consists of the approach applied in this research which is a restricted variable cost function. The restriction in the variable cost function could reflect technological, regulatory, or production constraints. The objective of the firm is to minimize the variable cost of production for a given level of output and a given level of quasi-fixed inputs. Factor demands are derived through Shephard's Lemma These factor demands will depend not only on output and the prices of variable inputs, but also on the quantity of the quasi-fixed variables. Long-run elasticities capturing the interrelationships between variable and fixed inputs can be obtained. Differences between short run and long run elasticities do not depend on an adjustment parameter, but rather on technological (and other) constraints. Therefore, estimation of a restricted short-run variable cost function provides a complete picture of short run and long run responses. However, this approach is not without its shortcomings. Most importantly, it does not provide a mechanism for measuring the time path between the short run and long run. To measure the time path between the short run and the long run would require the modeling of an explicit time adjustment process. This can be accomplished using the third approach- referred by Berndt et al. as Third Generation Dynamics.

A unique feature of this third approach is that the speeds of adjustment of quasi-fixed inputs are endogenous and not fixed. Thus, one could "map out" the time path of quasi-fixed inputs from the short run to the long run. Empirical applications of these models can become quite complex, especially when there are several inputs involved. In addition to the specification of a cost or production function, an explicit specification of a cost adjustment process and of expectation formation must be applied. These relationships may not be so easily discernible in a multi-faceted and technology-changing industry such as telecommunications. Also, measuring the time path of adjustment may be more of a crucial point in, say, energy markets in which the timing of energy price changes is important, but not so much in the study of telecommunications.

A recent approach, perhaps a fourth generation of models, emerged in the 1990's, in which the focus is to explore the possible endogeniety of pricing in the output market. The key assumption of these models is the existence of imperfect competition in the output market. An example of this approach is Kahai et al (1996), in which they study the "dominance" or market power of AT&T in the interstate long distance market in the post-divestiture period. Their approach utilizes the dominant firm/competitive fringe model for the estimation of the elasticity of fringe firm supply, market demand and existing market share.

Research Issues

A starting theoretical point to this research is the question: Is there a natural monopoly in the telecommunication industry? The concept of a natural monopoly, which centers around the notion of cost subadditivity, means that a single firm can produce any combination of outputs at a lower cost than that produced by several firms. Computationally, economies of scale for a total cost function are equal to the inverse of the cost-output elasticity. One can also compute output-specific economies of scale. Such economies of scale would result from a less-than proportional increase in the cost which is specific to an output when the level of that output increases, holding all other outputs constant. For single-output firms, the presence of economies of scale is sufficient to produce cost subadditivity. For multi-output firms, on the other hand, cost subadditivity requires the presence of economies of scope as well.

Hence, my next theoretical question to consider is: Does the telecommunications industry exhibit economies of scope? Economies of scope exist when joint production of an industry's outputs is less costly than their separate production. They can be computed as

$$\sum C_j(Q_j) - C(Q_1, Q_2, \ldots, Q_n),$$

where $C_j(Q_j)$ is sum of the stand-alone costs of outputs Q_j ($j = 1, 2, \ldots, n$), and the term on the right is the joint cost of producing those outputs. In order to compute economies of scope for a particular firm, that firm must obviously produce at least two distinct types of outputs. When joint costs are present as in telecommunications, it is difficult, if not impossible, to separate the costs of producing each output. Similarly, in order to compute overall economies of scope for a given industry, there must exist firms that produce only one type of output, say toll service, while others produce only local service plus firms that produce both types of services. This is necessary in order to isolate stand-alone costs versus joint costs. However, the changing structure of the telecommunications industry does not make it possible to estimate economies of scope in this study for the *entire* sample period. Prior to divestiture (1960-1984), the RBOCs and the independent companies produced both types of services. Since divestiture and until the Federal Telecommunications Act of 1996, AT&T (and other long distance companies) were allowed to provide only toll service, while the RBOCs and ILECs were allowed to provide only local service (including intraLATA toll). Now, most companies are allowed to produce both types of services, but considering that the post-FTA sample period is small (1996-1999), it would be unlikely for the model to produce significant results.

Another theoretical question to address in this research is how to measure competition. The economic literature is full of ideas, but the question is which is the most suitable within the context of regulation? Some have suggested market-level measures, such as the concentration ratio and the Herfindal-Hirschman index. Others have suggested firm-level measures, such as market share, the Lerner index, or firm profitability. There are also indirect measures, such as increased productivity, increased technological deployment, diminished economies of scale and scope, lower output prices, and increased efficiency. More recently, there are new measures of competition geared toward local exchange competition. They include the number of signed interconnection and resale agreements between incumbent LECs and competitive LECs, the level of resale discount rates for resellers of local exchange service, and the number of certified competitive local exchange carriers. Faced with a variety of measures, the appropriate choice will clearly depend on the nature of the study, the specifications of the model, and the availability of data. For the purpose of my research, the specification of a translog variable cost function limits the number and options of competition measures. Therefore, I rely on indirect measures of competition such as technology indicators, price markups, and diminished economies of scale. The new measures of local exchange competition are better suited for a cross-sectional study of several LECs in all states[1].

Another theoretical question crucial to my study is the measurement of technological change. Typically, technological change is measured as the rate of change of the production function (or cost function) with respect to time. It represents a one period reduction in cost due to the passage of time, or the advancement of technology. In cases where a proxy is used for time as a measure of technology, as in my case, the definition is simply the derivative of the cost function with respect to the technology variable(s). But which technology measure is suitable?

Empirical literature of telecommunications studies is full of proxy measures for technology. The identities of those variables have changed over times in correspondence with changes in the level of and nature of technology. Early attempts have included the percentage of customer dialed long distance calls, the percentage of direct-dial equipped phones, or the percentage of electronic switches. As technology progressed further, newer proxies were used such as the deployment of fiber optic cable and lines, the deployment and subscribership of integrated switch digital networks (ISDN), the percentage of digital switches, and the percentage of digital subscriber (DSL) equipped lines. It is admittedly difficult, if not impossible, to find technological variables that reflect the state of technology accurately and

[1] The information was not completely available at the start of this research.

comprehensively. At best, all measures are approximations of the true level of technology.

DESCRIPTION AND SOURCES OF DATA

Most of the data in this research was obtained from the Federal Communication Commission's Statistics of Communications Common Carriers (SCCC). These annual publications, first published in 1941, contain extensive information on company and industry cost, revenues, rates, network infrastructure, financial and economic data, historical data and international data. The number and category of reporting companies have varied over the years due to the changing nature of the industry and due to changes in the reporting requirements. In 1999, there were fifty-two reporting Incumbent Local Exchange Carriers (ILECs), accounting for more than 90% of the nation's local telephone service. Of those companies, those affiliated with the five largest holding companies were required to file the most extensive data. In 1999, those companies were Bell Atlantic, BellSouth, GTE, SBC, and US West. The remaining 10% of the local exchange companies (those making less than $114 million in annual revenues in 1999) were not required to file information with the FCC.

Competitive Local Exchange Carriers (CLECs) and wireless service providers are exempt from filing detailed information with the Commission. Information concerning the price level of wireless telephone service was obtained from the FCC's Trends in Telephone Service, published by the Industry Analysis Division of the Common Carrier Bureau. It is assumed in this research that the average number of wireless calls is ten calls per day. This best approximates the calling patterns of both residential and business customers when aggregated into one measure.

As of 1999, there were seven-hundred interexchange carriers (IXCs) or companies that purchase access from local telephone companies in order to provide long distance services. There is limited detailed information on IXCs in the FCC's SCCC reports, except by AT&T, which was considered a dominant carrier until 1996. Following 1996, detailed reporting requirements for AT&T were eliminated. Additional information concerning AT&T, MCI and Sprint were obtained directly from the companies annual reports and SEC 10-K reports. Some information was also obtained from the companies' respective websites.

Network infrastructure data was obtained from the FCC's SCCC reports (up to 1987). Due to changes in the FCC's reporting requirements, telephone switches are no longer categorized by technology as of 1987. The categorization of technology now is reported with respect to access lines. Data is classified as either analog or digital access lines and voice channel miles. To overcome the change in data re-classification, alternative sources were sought in order to complete the data sample. Information regarding recent network infrastructure and technological measures were obtained from the FCC's Automated Reporting Management Information System (ARMIS) reports. These reports have been published annually since 1991, and hence contain only recent data. Data for the years 1988-1991 were obtained from various online reports from the FCC's website.

Infrastructure data in the ARMIS reports pertains only to the networks of local exchange carriers. The data is compiled on a yearly basis for the entire nation. Switches are defined by ARMIS as assemblies of equipment and software designed to establish connections among lines and between lines and trunks. Switches include tandems, local switches, class 5 switching machines and any associated remote switching machines. The variable Modern Switches in this research consists of the percentage of electromechanical switches (e.g., step-by-step and crossbar), analog stored program controlled (ASPC), and digital stored program controlled (DSPC) of total switches. This technology variable is intended to measure the extent of the deployment of "state-of-the-art" or modern switches. Hence, the definition of modernity (i.e., the numerator of this ratio) changes over the years. The first adoption dates of digital central office equipment and of fiber optic transmission equipment by an Independent LEC were 1976 and 1977 respectively. The adoption dates for the Bell companies were approximately four years later. Therefore, data for the Modern Switch variable in this model extends from 1970 (earliest published data), while data for the Fiber deployment variable extends from 1980, with the first fiber optic deployment for telecommunications use. The 1980-1990 data was obtained from the FCC website.

The variable measuring fiber deployment consists of total fiber miles per year, which is the sum of fiber strands[1] terminating at the central office and fiber terminating at the customer's premises. Fiber terminated at the customer's premises

[1] Fiber miles measure each strand of fiber within a cable. So, if there are ten strands of fiber along one mile, this would be computed as ten fiber miles.

consists of DS0, DS1, DS3 and higher rates[2]. The inclusion of a wide range of transmission speeds allows for a wide coverage of residential and business usage. Investment in fiber optics is undertaken not only by local exchange carriers but also by interexchange carriers. My data sample, however, pertains only to the local exchange carriers, as no information was available for interexchange carriers. This serves my purpose of investigating the effects of deregulation and competition on the investment decisions of telecommunications carriers, the majority of which (for most of the sample years) are local exchange carriers. Moreover, the exclusion of interexchange carriers is also consistent with the switching equipment data which also applies only to local exchange carriers.

Cost is defined as operating costs, which include plant specific operations costs, such as central office switching , transmission expenses and cable and wire facilities expenses; plant non-specific operations expenses, such as access, power, testing, network administration and engineering; depreciation and amortization expenses; customer operations expenses, such as marketing and service expenses; corporate operations expenses; and general and administrative expenses, including legal expenses and R&D. Operating costs were obtained from the FCC's SCCC's

[2] DS stands for digital signal. DS0 is a signal format defined by the American National Standard Institute (ANSI) that operates at 64 kilobits per second (kbps). A DS0 signal format can carry any one of the following: an uncompressed voice call, a compressed high quality voice call, 2 or more compressed voice calls, data at speeds up to 56 kbps, or data at speeds up to 64 kbps, if the underlying transmission equipment has clear channel capability. DS1 carries 1.544 megabits per seconds (mbps). DS2 has been installed in Japan. U. S. companies requiring more capacity than DS1 have installed DS3, which carries 44.736 mbps. DS3 is also used for access to network services such as Asynchronous Transfer Mode (ATM) or Switched Multi-Megabit Data Service (SMDS). DS3 is typically transported on coax, fiber or microwave facilities (Source: TRA Understanding the Basics of Communications Networks, 1998).

historical tables. They include costs for AT&T, the RBOCs, GTE and mid-sized LECs for the period 1960-1983, then they include all of the former plus MCI and Sprint. Cost is normalized by the price of materials, which is the producer price index for intermediate materials, supplies and components for the manufacturing sector obtained from the Economic Report of the President. In order to avoid double counting, cost figures were adjusted by removing access charges (sometimes reported as access and line connection charges) and R&D expenses. Data for access charges (or interconnection or line cost) were not available for the entire sample. Access charge data for MCI for the years 1989-1996 were estimated based upon average of the three largest IXC's (approximately 25% of operating cost). R&D for MCI expenses were estimated at 1% (one percentage point less than the actual average percentage rate for AT&T to account for difference in firm size) of total operating costs.

Revenues are measured as total operating revenues. Revenues of LECs and the major IXCs were obtained from the FCC's SCCC reports. Revenues for other IXCs and resellers [3] were also obtained from the FCC's SCCC reports. Additional information was obtained directly from company annual reports. Revenue information for MCI begins in 1984 while revenue for Sprint begins in 1982. All revenue figures were adjusted by deducting revenues of international operations, access revenues and wireless revenues. International revenues for MCI and Sprint for the early years of

[3] Other IXCs and Resellers include LCI d/b/a Qwest, Global Crossing, Cable and Wireless USA, Excel and VarTec. Data includes information for 1985-1999 for Global Crossing and Cable and Wireless USA; and 1994-1999 for all companies.

the sample (1982-1985) were not completely available[4]. Estimates based upon average trends were used in lieu of the missing data.

Output is measured as the total annual number of calls in the U. S. Local output is the total annual number of local exchange calls in the U. S. Toll output consists of interstate calls and intrastate toll calls, including intraLATA toll calls. Output price is calculated as the average revenue per call. Prices were indexed to 1996 prices and deflated by the GDP Price Deflator.

Data on physical capital stock was obtained from the FCC's SCCC. It was further adjusted through the perpetual inventory method, so that capital accumulates pursuant to the following process:

$$K_t = I_t + (1 - \delta_K) K_{t-1} \quad ,$$

where K_t and I_t represent the stock of capital and investment in period t and δ_K is fixed rate of depreciation. δ_K is equal to 10% (approximated from various data sources on capital investment in telecommunications), and the rate of return on capital investment is equal to 11% (the average rate of return in the regulated utility industry). The capital investment price index is the producer price index of capital goods in the manufacturing sector, obtained from the Year 2000 Economic Report of the President.

[4] International operations for MCI and Sprint in the early years were not a significant part of total operations. International data was not reported in the FCC SCCC reports for MCI for the years 1982-1984. Similarly, for Sprint in the years 1984-85. A designation of international revenues could not be located in the companies respective annual reports.

R & D capital consists of the accumulation of deflated R & D expenditures. Data on R&D capital was obtained from the FCC SCCC reports and from company annual reports. Data was adjusted according to the perpetual inventory method in a similar manner to physical capital above. However, as in Nadiri and Nandi, R&D investment was lagged by four years to account for a longer gestation period for this type of investment. The depreciation rate is assumed to be 10% (approximated from various data sources on capital investment in telecommunications), and the rate of return on R&D investment is assumed to be 5% (also approximated from various data sources on capital investment in telecommunications). The price of R&D investment was obtained from the National Science Foundation's Survey of Industrial Research and Development. The index used in this study is a company-funded R&D expenditure index (stated in 1996 dollars). The funds are predominately the company's own, but also include funds from outside organizations such as other companies, research institutions, universities and colleges, non-profit organizations and state governments.

Wages were obtained from data on total employee compensation and number of employees in the FCC's SCCC reports. Standard assumptions of time allocation are made, such as 40-hour work weeks and thirty-day months. Wages reflect both full-time and part-time employment.

Several dummy variables were used, and some were considered, in the estimation process, One such variable measures the effect of the divestiture of AT&T

in 1984. It is equal to zero in the years prior to 1984 and is equal to one in the years following and including 1984. A regulatory variable (REG) intended to measure the effects of recent deregulatory trends in telecommunications is also used. It is equal to zero for the years prior to 1991 and one for the years following and including 1991. A separate dummy variable was considered for the Federal Telecommunications Act (FTA) of 1996. However, due to the limited number of data points, the effect of the FTA was grouped together with the other regulatory effects in the variable REG. Occasionally, the FTA dummy variable was used as an instrumental variable.

Several instrumental variables (IVs) were considered, such as the lagged values of wages, physical capital, R&D capital and output prices. Additionally, the growth rates of GDP, population, access lines, and service sector size were sometimes used as IVs. Other IVs, such as number of CLECs, number of resellers, and number of wireless service providers have proven to be less effective, and therefore were not used in the final estimations.

Finally, some information pertaining to the years prior to 1970 was obtained directly from I. Nadiri and B. Nandi. Necessary adjustments, such as updated indexation, were made in order to make the data consistent with the remaining sample.

TREATMENT OF MISSING DATA

Missing data consist of a few missing observations on international telecommunications revenues, interconnection costs, access charges, fiber optic deployment and R&D expenses. Values for most missing data were extrapolated using one of two similar procedures by Shazam and Excel. Excel's procedure consists of a forecast function, which calculates or predicts a future value along a linear trend using existing values. The actual estimation procedure is a simple linear regression. Shazam's forecasting procedure is similar to Excel's. It consists of a forecast command, which predicts values over a specified range using simple linear regression.

Data for which the range of missing data points was relatively small were generated by Excel. Data for which the range of missing data points was relatively large were extrapolated using the Shazam procedure. Missing data points which were a part of an obvious consistent trend, or which tended to maintain a uniform average, were approximated using straightforward calculation of arithmetic averages.

THE EMPIRICAL MODEL

Description of the Model

In this research, I apply a multi-output and multi-input model similar to the one used by Nadiri and Nandi (1997 and 1999)[1]. The model allows for the simultaneous estimation of the demand and cost structures of the industry through a set of revenue share equations, input share equations, a cost equation and output demand equations. The model depicts both a short run and a long run version. The production function for the U. S. telecommunications industry is given by:

$$F\,[\,Q, V, Vs, \Delta\,Vs, T\,] = 0\,, \tag{1}$$

where Q is a vector of outputs (local and toll services), V is a vector of variable inputs: labor and materials, Vs is a vector of "semi-variable" or quasi-fixed inputs: physical and research & development capital, Δ Vs is a vector changes in the quantities of quasi-fixed inputs, and T is a vector of technology measures (defined below).

The model proceeds with the argument that a firm, regulated or not, will attempt to minimize variable cost subject to a given level of capital and technology. Further, it is assumed that the telecommunications firm faces an inelastic demand for

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[1] Nadiri, M. I., and Nandi, B., 1997, pp. 319-347, and Nadiri, M. I., and Nandi, B., 1999, pp. 488-498.

local telephone service and an elastic demand for toll service. Input markets are assumed to be competitive, so the firm has no market power over input prices.

The overall objective of the telecommunications firm is to maximize the expected value of the flow of funds, or equivalently, to minimize the expected value of the costs of production. This is depicted as follows:

$$\sum_{s=t}^{\infty} E(t)\ \alpha(t, s)\,[\,W(s)\,V(s) + P_{i\,I}(s)\,I(s)\,], \tag{2}$$

where E (t) is the expectation operator, α (t, s) is the discount rate between periods t and s, W (s) is the vector of variable input prices in period s, V (s) is a vector of variable inputs in time period s, $P_{i\,I}$ is the acquisition prices of the quasi-fixed inputs, and I (s) is a vector of gross investment levels in time period s.

The problem facing the firm can be solved in three steps. The first step is to determine the demand for the variable inputs whereby the firm minimizes its variable cost function. The minimized variable cost function depends on variable input prices, output quantities, quasi-fixed inputs, gross investment levels and the rate of technological change. This result can be depicted as follows:

$$VC = F\,(W, Q, Vs, I, T)\,, \tag{3}$$

where VC is variable cost, W is the vector of variable input prices and I is the vector of gross investment levels.

The demand functions for the variable inputs are obtained by applying Shepherd's Lemma. Input demand is the partial derivative of the variable cost function with respect to the respective input price, as shown below:

$$D_i = \frac{\partial VC}{\partial W_i} (W, Q, Vs, I, T) \tag{4}$$

The demand for labor and materials is dependent on capital accumulation conditions characterizing the investment relationship, I, in equation (4). The accumulation process of capital in this model is assumed to be the standard perpetual inventory method, in which the time series of the stock of capital is computed from the dollar values of investment and the prices of capital[2]. The accumulation process of physical capital is as follows:

$$K_t = I_t + (1 - \delta_K) K_{t-1} , \tag{5}$$

where K_t is the stock of physical capital in time period t ; I_t is gross investment in physical capital in current dollars; δ_K is depreciation, and K_{t-1} is the physical capital stock in time period t-1.

The accumulation process of R&D capital is as follows:

$$RD_t = I_{t-4} + (1 - \delta_{RD}) RD_{t-1} , \tag{6}$$

[2] Usher, Dan, 1980, The Measurement of Capital, National Bureau of Economic Research, Conference on Research in Income and Wealth, the University of Chicago Press, Chicago and London.

where RD_t is the research and development capital stock in time period t ; I_{t-4} is gross investment in research and development lagged four years; δ_{RD} is depreciation, and RD_{t-1} is the research and development capital stock in time period t-1.

Equations (3) and (4) comprise the solution to the short-run input demand equilibrium problem. The second step is to determine the prices of outputs. The industry is assumed to produce two outputs: local and toll telecommunications services. Once optimal output quantities are determined as a result of variable cost minimization, the firm determines the corresponding optimal prices.

When one applies the assumption of profit-maximization, revenue share (of variable cost) equations can be derived, which in turn cause output to be endogenous. The firm determines the level of output(s) at which marginal revenue is equal to marginal cost. Following conventional economic theory and the notation of Fuss and Waverman[3], the revenue share equations are derived as follows:

$$\frac{\partial \log C}{\partial \log Y_i} = \frac{\partial C}{\partial Y_i}\frac{Y_i}{C} = MR_i \frac{Y_i}{C} = \frac{P_i(1 + 1/\varepsilon_i)\, Y_i}{C} \qquad (7)$$

where MR_i, the marginal revenue for each output, is substituted in for $\partial C/\partial Y_i$, the

[3] Fuss, M., and Waverman, L., 1977, Multi-product, multi-input cost functions for a regulated utility: The case of telecommunications in Canada, presented at the N. B. E. R. Conference on Public Regulation, Washington, pp. 288-289.

marginal cost of each output, and ε_i is the price elasticity of demand for each output. The fourth expression is derived by applying the conventional Ramsey relationship[4] which relates price markups to the price elasticity of demand and by applying the profit maximization condition of MR = MC. We obtain the following expressions:

$$\frac{MC_i - P_i}{P_i} = 1/\varepsilon_i = \frac{MR_i - P_i}{P_i}, \text{ or} \tag{8}$$

$$MR_i = P_i(1 + 1/\varepsilon_i) \tag{9}$$

Multiplying both sides by $\frac{Y_i}{C}$, we obtain

$$\frac{P_i(1 + 1/\varepsilon_i)\, Y_i}{C} \tag{10}$$

Denoting $P_i Y_i / C$ as R_i, for revenue share, we obtain

$$R_i = \frac{\partial \log C}{\partial \log Y_i} (1 + 1/\varepsilon_i)^{-1} \tag{11}$$

Therefore, the revenue share equations (stated explicitly in the next section) define the product market equilibrium conditions. The revenue shares do not have to sum to unity, since the firm is not constrained to earn zero economic profits.

The third step is to determine the demand for the quasi-fixed inputs. The solution to this step constitutes the long run equilibrium condition. It is obtained by

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[4] Tirole, J., The Theory of Industrial Organization, MIT Press, Cambridge, Massachusetts, 1995, p. 137.

substituting the variable cost function and the capital accumulation equations into the expected value of the costs of production (i.e., equation 2). Demand functions for the quasi-fixed inputs are derived using the Envelope Theorem. The theorem postulates that quantities of fixed (or quasi-fixed) inputs are at their long run equilibrium level when their shadow prices are equal to their rental prices (or the opportunity cost of funds of their acquisition). The resulting demand equations (stated below) then comprise the long run equilibrium conditions. Finally, there is an element of dynamics in this short run set up. It is derived from the fact that the demand for the variable input depends on the quantities of the quasi-fixed inputs which continually adjust over time. Therefore, as the demand for physical capital and R&D change over time, the demand for labor is also affected.

As a final note on the decision process of the telecommunications firms in this model, I address the Averch-Johnson effect. Averch and Johnson[5] argue that regulated utilities have an incentive to over-invest in capital. They contend that since rate-of-return regulation guarantees the regulated firm an allowed rate of return on the cost of capital, the firm will have an incentive to over-invest in capital. In other words, rate-of-return regulation would bias the choice of inputs away from the optimal levels. This is provided, of course, that the rate of return exceeds the cost of capital. Whether the Averch-Johnson argument is correct is subject to continuing debate. The empirical literature is replete with studies offering mixed results (Spann 1974, Peterson 1975, Cowing 1978 and Joskow and Rose 1989). It can be argued, as in

[5] Averch, H., and L., Johnson, 1962, Behavior of the firm under regulatory restraints, American Economic Review, 52, pp. 1052-1069.

Nadiri and Nandi (1997), that whether or not the AJ effect is accurate, a firm (regulated or otherwise) will attempt to minimize variable cost subject to a given level of capital and technology. Therefore, I argue that the variable cost model is valid regardless of the AJ effect.

Furthermore, unlike many translog cost functions which assume output is exogenous especially in the context of regulated utilities, I assume (as do Nadiri and Nandi 1997) that output is endogenous. This does not preclude the presence of regulation in a legal sense, but it may preclude it in an economic sense, if the regulatory restraints imposed by regulators are not economically binding over the optimizing decisions of the firm. In other words, if the regulation-imposed rate of return on capital investment equals or exceeds that of the market rate of return, then the presence of regulation is effectively neutral. In this case, a monopolist will likely behave as a profit-maximizing monopolist. But considering that trends in regulation are frequently changing and sometimes unforeseen, regulation is treated in this model as an external factor freely affecting the structure of the model.

The Short Run Model

The short run model consists of a variable cost function, a labor share function, two revenue share functions, and two output demand functions. As stated above, a variable cost function, unlike a total cost function, includes the *quantities* of fixed factors, in this case capital, in the equation not their prices. The translog cost function of this model is as follows:

$$
\begin{aligned}
&LCost=bo+b_L\,LW+g_1\,REG+g_2\,DIV+Z_1\,LMod+Z_2\,LFib+b_1\,LY1+\\
&b_2\,LY2+b_k\,LK+b_r\,LRD+b_{LL}\,.5\,(W2)+b_{11}\,.5\,(LY1\ LY1)+\\
&b_{22}\,.5\,(LY2\ LY2)+b_{12}\,.5\,(LY1\ LY2)+b_{kk}\,.5\,(LK\ LK)+\\
&b_{rr}\,.5\,(LRD\ LRD)+b_{rk}\,.5\,(LK\ LRD)+.5\,(Z_{11}\,LMod+Z_{22}\,LFib)^2+\\
&g_c(REG\ LK)+g_c\,(REG\ LRD)+g_{1w}\,(LW\ REG)+g_{Ya}\,(LY1\ REG)+\\
&g_{Ya}\,(REG\ LY2)+Z_{1w}\,(LW\ LMod)+Z_{2w}(LW\ LFib)+\\
&b_{L1}(LW\ LY1)+b_{L2}(LW\ LY2)+b_{Lr}\,(LW\ LRD)+b_{Lk}\,(LW\ LK)+\\
&b_{k1}(LY1\ LK)+b_{k2}\,(LY2\ LK)+b_{r1}(LY1\ LRD)+b_{r2}\,(LY2\ LRD)+\\
&Z_1(LY1\ LMod)+Z_2(LY2\ LFib)+Z_1\,(LY2\ LMod)+Z_2(LY1\ LFib)+\\
&Z_1(LK\ LMod)+Z_2(LK\ LFib)+Z_1\,(LRD\ LMod)+Z_2\,(LRD\ LFib) \qquad (1.1)
\end{aligned}
$$

where LCost is the log of industry variable cost, LW is the log of the industry average wage level, REG is a dummy variable capturing the effects of deregulation (it takes the value of one from 1991 to 1999 and the value of zero otherwise), DIV is a dummy variable reflecting the AT&T divestiture of 1984 (it takes the value of one from 1984 to 1999 and the value of zero otherwise), LMod is the log of the percentage of modern switches of local exchange carriers (defined according to the current state-of-technology), LFib is the log of the nation-wide number of deployed fiber optic miles of local exchange carriers since 1980, LY1 is the log of local service output measured as the nation-wide total number of local calls, LY2 is the log of toll service output measured also as the nation-wide total number of calls, LK is the log of industry physical capital stock, and LRD is the log of industry research and development capital stock.

The usual restrictions apply, namely symmetry, additivity, and homogeneity. Symmetry requires that $b_{ij} = b_{ji}$, for i , j =1, 2, and $b_{mn} = b_{nm}$, for m , n = k, r. Additivity requires that the cost shares must sum to unity, so $\Sigma\, b_L + b_M = 1$. Homogeneity implies that if the input variables in the cost function are multiplied by a given proportion, the cost function will increase by that proportion. Homogeneity in variable input prices (i.e., wages and price of materials), given the quantity of fixed factors and output, can be achieved by normalizing the cost function. This is carried out by dividing variable cost and wages by the price of materials. This can be illustrated in general notation[6] as follows:

$$F(x, \alpha y) = \alpha F(x, y), \qquad \text{for } \alpha > 0.$$

If we set $\alpha = 1/y^*$, then $F(x, y / y^*) = F(x, y) / y^*$.

Certain restrictions are imposed on the technology and regulatory variables. Following the consideration of several alternatives (as discussed in the Alternative Models chapter), I applied the following restrictions: the deployment of modern switches is assumed to have the same effect on both types of outputs. That is, the coefficient of the interactive term (LMod LY1) is the same as that for (LMod LY2).

[6] See Morrison, et al (2000), p. 327.

This assumption is restrictive, but consistent with the notion that local and toll services are complements in production and consumption.

Further more, the deployment of modern switches is assumed in this model to have the same effect on both types of capital. This is consistent with the fact that company-specific expenditures on R&D and capital are often earmarked toward a specific project or a new invention (e.g., a new design of digital switches). I have applied the same restrictions to the fiber deployment variable for the same reasons given above. Investment in fiber optics is undertaken not only by local exchange carriers, but also by interexchange carriers. My data sample, however, pertains only to local exchange carriers, as no information was available for interexchange carriers. This serves my purpose of investigating the effects of deregulation and competition on the investment decisions of established regulated local exchange carriers (including pre-divestiture AT&T). Moreover, the exclusion of interexchange carriers is consistent with our switching equipment data which pertains also to local exchange carriers only. Regulation, in this model, is also assumed to have the same effects on both types of outputs. The rationale for this assumption is to allow our regulatory variable, which is designed to capture the effects of deregulation in both the toll and local markets, to measure an overall industry effect of deregulation

Regulation is also assumed to have the same effects on both types of capital. The rationale for this assumption is that generally investments in capital and R&D tend to go hand in hand. Most R&D projects are either earmarked toward a specific new technology (e.g., digital technology) or as a particular new innovation of an existing process or equipment (e.g., Signaling System Number 7[7]). By the same token, most new investments in capital equipment are accompanied by supporting research, test studies and documentation (i.e. , R&D). Furthermore, unlike the Nadiri and Nandi model which incorporates "time" as a proxy for technological change, this model incorporates direct measures of technology, namely the percentage of total electronic and digital switches of local exchange carriers and the total number of deployed fiber miles to central offices and to customer premises. The choice of these variables is based upon the general consensus[8] in the industry today that the two most significant technological advancements in telecommunications in the recent past are digital switches (or central offices) and the invention of fiber optic transmission.

The Input Share Equations

Differentiating the cost function with respect to input prices gives the cost share equations. The labor share equation is:

$$\begin{aligned} SL = {} & b_L + b_{LL}\, LW + b_{L1}\, LY1 + b_{L2}\, LY2 + b_{Lk}\, LK + b_{Lr}\, LRD + \\ & g_{1w}\, REG + Z_{1w}\, LMod + Z_{2w}\, LFib \end{aligned} \tag{1.2}$$

[7] Signaling System Number 7 (SS7) is an international standard common channel signaling system. It is used between public network switches and LEC switches.

[8] See Zhou, Chappell, McMaster, and Lee.

The materials share equation is derived similarly. In this model, there are only two variable factors of production: labor and materials. Since the sum of the shares must equal one, $b_L + b_m = 1$. The share of materials can be derived as: $S_M = 1 - S_L$. Therefore, there is only one variable factor share equation to be estimated in this model and that is the share of labor. The choice was arbitrary as to which equation to eliminate.

Since the sum of the two input shares equals one, we must expect a non-zero contemporaneous covariance between the disturbances in different equations. But there is no reason to expect the same disturbance variance in different share equations. In other words, the model allows for contemporaneous correlation across equations.

The demand Equations:

In regulated industries, it is often reasonable to assume, as we do in this model, that demand is exogenous. The demand equations are:

$$LY1 = a_o + a_1\ LP1 + a_2\ LGDP + (1-a_2)\ LPOPU + a_3\ Llines \tag{1.3}$$

$$LY2 = d_o + d_1\ LP2 + d_2\ LGDP + d_3\ LLines + d_4\ LPWire\ , \tag{1.4}$$

where LP1 is the log of the price of local service, LGDP is the log of real GDP, LPOPU is the log of population, Llines is the log of the number of access lines, LP2 is the log of the price of toll service, and LPWire denotes the log of the price per call of wireless telecommunications services.

LPWire is an new variable intended to measure the effects of wireless services as an emerging substitute or complement to traditional telecommunication services. Other measures have been considered, such as the number of wireless subscribers, the average length of wireless calls, the average wireless monthly bill, and the number of cell cites, but estimation results were not significantly different. Considering that only recently have wireless services been especially prevalent and affordable, published industry data is limited. And so with relatively few observations, the true effects of wireless services may not be quite pronounced.

<u>The Revenue Share Equations</u>:

The revenue share equations are:

$$R1 = (b_1+b_{11}\,LY1+b_{12}\,LY2+b_{L1}\,LW + b_{k1}\,LK+b_{r1}\,LRD + g_{Ya}\,REG+Z_1\,LMod+Z_2\,LFib)(1+1/a_1)^{-1} \tag{1.5}$$

$$R2 = (b_2+b_{22}\,LY2+b_{12}\,LY2+b_{L2}\,LW + b_{k2}\,LK+b_{r2}\,LRD + g_{Ya}\,REG+Z_1\,LMod+Z_2\,LFib)(1+1/d_1)^{-1} \tag{1.6}$$

One advantage of minimizing variable cost as opposed to total cost is that it allows for variation in the utilization of quasi-fixed inputs. So, rather than minimizing total cost subject to the levels of output, one can minimize variable cost subject to the level of output and the levels of quasi-fixed inputs.

The short run optimization problem of the telecommunications firms in this model consists of choosing the levels of variable inputs, subject to the levels of quasi-fixed inputs, the level of technology and the state of regulation. In addition, optimal output quantities are determined subject to output prices. The entire system of equations consists of the VC function, the labor share equation, the two revenue equations and the two output demand equations.

Estimation Procedure and Issues:

The model is non-linear in variables and coefficients and it consists of several simultaneous equations. Therefore, I apply the system-procedure of non-linear three-stage least squares (3SLS). The advantage of using 3SLS as opposed to a single-equation procedure such as 2SLS is that single-equation methods, in general, lead to estimates that are not asymptotically efficient[9]. The reason for this lack of efficiency is that single-equation procedures fail to take into account the correlation among the disturbances across equations. In other words, they fail to utilize all available and relevant information.

The 3SLS procedure consists of: (1) obtaining 2SLS estimates[10] ; (2) estimating the structural equations' errors using these estimates, and estimating the variance-covariance matrix; and (3) applying generalized least squares (GLS) to the

[9] Kmenta, Jan, 1986, Elements of Econometrics, Second Edition, Macmillan Publishing Company, New York, pp. 695-701.

[10] 2SLS consist of (1) Estimating the reduced form equation(s), and (2) Using the estimated values from step (1) and the included exogenous variables as regressors in an OLS regression.

entire system consisting of stacked equations taking account of non-zero correlations between the disturbances in different equations[11].

It is possible to iterate the 3SLS procedure, as is performed in this model through the software package. This entails using the original 3SLS estimates to create new estimates of the structural disturbances. The procedure is repeated until there is no change in the estimated coefficients. The resulting estimates have the same asymptotic properties as the original 3SLS estimates.

The difficulty with estimating *non*-linear models lies with the practical aspects of solving the derivative expressions which inherently contain power terms. Aside from the relative difficulty of solving an equation with power terms in comparison to a linear one, such an equation contains not one but several solutions. The goal of the optimization process of nonlinear regressions is to search for a *global* minimum, not just *a* minimum. Therefore, regression runs, driven by a specified search procedure, becomes tedious and time-consuming. Some solutions are, however, immediately ruled out by the researcher as contrary to economic theory. In addition, a level of "tolerance" is typically specified in advance, which defines the "tolerable" value of zero (typically at .00001). This reduces the search time and confines its scope. The final goal of the non-linear regression, thus, is for the model to converge, which means

[11] Kennedy, Peter, 1985, A Guide to Econometrics, Second Edition, MIT Press, Cambridge, Massachusetts, pp. 134-136.

that the search procedure has reached a global minimum value of the objective function.

There are many search procedures in the literature- many of which are offered in computer software packages. They all begin with the idea of applying suggested starting values of the estimated coefficients. These suggested values may be the result of an educated guess based upon knowledge of theory or from direct inferences from previous applied research or a direct inference from a linear approximation to the model in question. In this research, I have taken advantage of all three sources. Earlier estimation attempts and model alternatives are described in Chapter Six. Direct inferences from previous work were drawn from sources cited in this research, in particular the Nadiri and Nandi 1997 study.

The estimation of non-linear models requires the use of a numerical optimization algorithm. Shazam uses a quasi-Newton method also known as a variable metric method. Each updating step of the algorithm requires a gradient (first derivative) estimate and Shazam provides for exact evaluation of the gradient. If exact derivatives cannot be computed, then Shazam uses a numerical approximation to obtain the gradient. Each updating step also requires an approximation of the Hessian (second derivatives). At model convergence, this approximation is then used as the covariance matrix estimate of the estimated coefficients.

There are also derivative-free methods of optimization, such as the downhill simplex method and the simulated annealing method. Both are often very effective in models with many variables, but they require more function evaluations than the derivative methods. As pointed out by Green[12], the latter methods are preferable in econometric work since models often involve complex functions with numerous terms in a summation. But derivative methods are appropriate as well.

Having covered the estimation issues of this model, I now turn to the estimation procedure. Since numerical procedures search for a global minimum, they are often called "search procedures"- the most simple of which is called a line search. Using Green's notation[13], the process begins with an initial value θ_0 at iteration t. If θ_t is not the optimal value for θ, then the algorithm computes a direction vector Δ_t with a step size λ_t, so that

$$\theta_{0+1} = \theta_t + \Delta_t \lambda_t$$

The search procedure searches for the optimal value of the function (F). The solution is the λ_t which satisfies

$$\partial F(\theta_t + \Delta_t \lambda_t) = g(\theta_t + \Delta_t \lambda_t)' \Delta_t = 0,$$

where g is the vector of partial derivatives of F(.) evaluated at $\theta_t + \Delta_t \lambda_t$.

The basis of Newton's method is a linear Taylor series approximation, in which the step size, $\lambda = 1$. This method is very effective in some models, but it can

[12] Green, William, 1993, Econometric Analysis, Fourth Edition, Englewood Cliff, New Jersey, Prentice Hall, p. 187.

[13] Ibid., pp. 189-189.

fail in others. If the function is not approximately quadratic, it can cause wide swings in the estimates and fail to converge.

For the sake of exposition, the model was first estimated without the aid of starting values. The results, as far as the demand equations, were unacceptable according to economic theory. Therefore, I applied starting values as recommended in most non-linear estimation. In Shazam, if a variable is not assigned a starting value by the researcher, a default value of one is automatically assigned. While a large set of starting values covering most variables was used in the actual estimation, only select values (mainly those pertaining to the demand coefficients) are reported below.

In order to ensure that one has definitely arrived at the optimal solution, it is recommended that one repeat the estimation process using different starting values. As complex as the procedure is, it still relies considerably on trial and error. If convergence occurs at different points, then the point with the lowest error sum of squares should be chosen. The model was tested for robustness by testing its sensitivity to the choice and fluctuation of starting values. The model solution was also tested for its global condition by running repeated regressions around the convergence point. Results are reported in Table A below.

The model was also tested for autocorrelation using the common Durbin-Watson (D-W) test. This method is recommended (see Kennedy, Judge, and Kmenta) for systems of equations, such as this model's, and for single-equation estimation. The results of the D-W test showed the presence of autocorrelation for all equations.

The presence of strong serial correlation means that the t statistics and R^2 will be exaggerated. This is because the presence of high serial correlation among the error terms along with the presence of independent variables that are increasing over time does not provide for much variability among those variables. This means that the estimated variance will be understated and so, the standard errors (the square roots of the variances) will be smaller Thus, the t statistics will be overestimated, since a t-statistic is equal to the estimated coefficient value divided by its standard error. There is some evidence of this particularly in the output demand equations (see Table 6 below).

When the regression disturbances are autoregressive, the least squares estimators of the regression coefficients are still unbiased and consistent, but they are neither efficient nor asymptotically efficient. The basic OLS assumptions of zero mean and no correlation between the disturbance term and the independent variables ensure that the estimates are unbiased and consistent. But failing to take account of the correlation between the disturbances across equations means that one is not taking full advantage of all the available information in the equations Thus, asymptotic efficiency is not attained.

There are several possible treatments and estimation procedures for dealing with autocorrelation[14], the most common of which is the Cochrane-Orcutt

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[14] Some of the common approaches are: (1) Transforming the data; (2) Including an autoregressive term in the model; (3) Building an autoregressive integrated moving average (ARIMA) model of the residuals; or (4) Taking first differences of the variables.

transformation. Under this procedure, the original regression equations are transformed into equivalent equations with independent disturbances. Its only drawback is the loss of the first observation. Another conventional procedure is the Prais-Winsten transformation method, which circumvents the problem by modifying the first observation. Both methods were considered, but the model failed to converge. Consequently, I applied another technique known as the method of first-differences.

The method of first differences consists of transforming the dependent and independent variables into first differences (i.e., $Y_t - Y_{t-1}$ and $X_t - X_{t-1}$). The resulting equations become as follows:

$$Y_t - Y_{t-1} = b\,(X_t - X_{t-1}) + \varepsilon_t - \varepsilon_{t-1}$$

The coefficients are then estimated using the method of least squares. The problem of autocorrelation is then eliminated or at least reduced. Looking at the autocorrelated error term, e_t, it is typically expressed as follows:

$$e_t = \rho\,\varepsilon_{t-1} + u_t \text{ ,where } 0 < \rho < 1 .$$

Denoting $(\varepsilon_t - \varepsilon_{t-1})$ as v_t, it follows that

$$E\,(v_t) = 0,$$

$$E\,(v^2_t) = 2\,\sigma^2\,(1-\rho)$$

$$E\,(v_t\,v_{t-1}) = E\,(\varepsilon_t - \varepsilon_{t-1})\,(\varepsilon_t - \varepsilon_{t-2}) \;= \rho\,\sigma^2 - \sigma^2 - \rho^2\,\sigma^2 + \rho\,\sigma^2$$

$$= \frac{-\sigma^2(1-\rho)}{1+\rho} \quad .$$

It follows that the new error term has zero mean and a constant variance. It also follows that the presence of autocorrelation (as measured by the last equation) is completely eliminated if ρ is equal to one. Theoretically, in the context of a least squares procedure, the error terms by definition are assumed to be independent normally distributed random variables. Hence the problem of autocorrelation, through the method of first differences, is eliminated.

If multi-collinearity is present, as is the case in most economic models especially when interactive terms are present, the standard errors of the coefficient estimates will be large. I found evidence of multi-collinearity in earlier estimation attempts. Ignoring this problem could adversely affect the power of hypothesis testing. Therefore, one remedy is to drop some interactive terms. I have experimented with various model specifications, as discussed in detail in the Alternative Models chapter, and were able to eliminate the problem.

Arriving at the Solution

In Table 1, I report the results of the search procedure for arriving at the optimal solution to our model. The search procedure is automatically carried out with every regression attempt. As stated previously, the process of non-linear estimation relies to some extent on trial and error. The reported results are only a select few of many repeated attempts. For the sake of brevity, I report the results of only a select estimation runs.

The "randomness" of the estimation process is greatly minimized by choosing reasonable starting values at the start of every process (refer to footnote in Table 1). As expected, the changes in the coefficients' starting values, in either an upward or a downward direction, cause changes in the values of the corresponding estimated coefficients. For example, changing the starting value of the toll output coefficient of the cost function (B_2) from 0.250 to 0.025, changes the corresponding estimated coefficient value from 0.42450 to 0.43770. The values of the model's other estimated coefficients are also affected, even if their starting values were not changed. For example, the R&D elasticity of cost (B_r) changes from –0.0656 to -.0117, even though its starting value did not change. The remaining coefficients remain much closer to the optimal results. The average gradient value is also affected by differences in the starting values. The average gradient value in this case changes from 0.2008137E-06 to 0.3727441E-04.

The continuation of Table 1 shows select results of three estimation runs as part of many repeated regression runs to illustrate the stability of the model. Overall, the estimated coefficient results remain stable and close to those of the optimal solutions. The average gradient values do not surpass that of the optimal solution's. The optimal solution to our short run model shows an average gradient value of 0.2008137E-06, which is very close to zero. This fact, along with the observation that, overall, the coefficient values of various repeated estimation runs (a sample of which is presented) remain fairly stable throughout the estimation runs, confirm the optimality of this solution.

As an added confirmation to my conclusion, it has been pointed out by Griffiths et al (2000)[15] that additional insights into the properties of the non-linear estimators can be gained by examining the second derivative of the sum of squares function, denoting the rate of change in the slope of that function. If, they argue, the sum of squares function is "flat" around the least squares coefficient estimate value, then the reliability of that estimate is more questionable, than the case in which that area is "steep". This is because in the flat area of the function, there are many other values of the estimate for which the function is only slightly greater than its minimum. Therefore, as part of my inspection of the robustness of the model, I looked for solutions around which the average values of the gradient are relatively higher.

Looking again at Table 1, it is noted that the average gradient value around the optimal solution (referring to the gradient values reported in the second and third rows) is approximately `0.176542-04`, which is larger (smaller in absolute terms) than the optimal solution's average gradient value. The average gradient values become larger around the optimal solution (see continuation to Table 1). This provides evidence of the solution lying in a "steep" area of the model's sum of squares function- which thus provides additional support for the solution's global nature.

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[15] Griffith et al, p. 718.

Table 1 Results of Robustness Tests- The Short Run Model

Starting Values[16]	Average Gradient Value	Estimated Coefficient Values	Remarks
bL .50 b1 .50 b2 .25 bk .80 brk .680 br -.750 bLk 1.50 bLr -1.0	0.2008137E-06	BL 0.27320 B1 2.0201 B2 0.42450 BK -1.4656 BR -0.65626E-01 A1 -0.45971 A2 0.21161 A3 1.4786 D1 -0.77293 D2 0.64911 D3 1.0178 D4 0.45705E-01	Optimal Solution Average gradient value is smallest (i.e., closest to zero)
bL .50 b1 .055 b2 .025 bk -.80 brk -.80 br -.750 bLk 1.50 bLr -1.0	0.3727441E-04	BL 0.27305 B1 1.6277 B2 0.43770 BK -1.2928 BR -0.11723E-01 A1 -0.44994 A2 0.25642 A3 1.4488 D1 -0.73511 D2 0.62901 D3 1.0433 D4 0.41880E-01	Coefficients are fairly stable. Values are close to those of the optimal solution. Average gradient value is larger than optimal solution's (indicating a steep function around the solution value).
bL 1.50 b1 .750 b2 .725 bk .80 brk .80 br -.50 bLk 1.25 bLr -1.0	0.1845101E-04	BL 0.24845 B1 1.8461 B2 0.45999 BK -1.4361 BR -0.47759E-01 A1 -0.48013 A2 0.18664 A3 1.4980 D1 -0.71615 D2 0.66725 D3 0.96574 D4 0.42343E-01	Again, the Average gradient value is larger than optimal solution's. Overall, estimated coefficients remain reasonably stable compared to optimal solution's.

[16] The following set of starting values is the complete set used in all regression runs, unless otherwise indicated in Table 1: bL .50 b1 .50 b2 .25 bk .80 brk .680 b11 .020 b22 .050 br -.750 bLk 1.50 bLr -1.0 brr .020 bL1 .050 bk1 .050 br1 .050 bL2 .050 bk2 .050 br2 .050 bLL .050 b12 .050 bkk .050 a1 -.70 d1 -.70.

Table 1- Continued

Starting Values	Average Gradient Value	Estimated Coefficient Values	Remarks
bL 1.50 b1 .50 b2 .25 bk .80 brk .80 br -.850 bLk .250 bLr 1.50	-0.1375604E-03	BL 0.24055 B1 1.6613 B2 0.42344 BK -1.2864 BR -0.15790E-01 A1 -0.39338 A2 0.27155 A3 1.4284 D1 -0.74956 D2 0.66688 D3 0.97710 D4 0.43372E-01	Coefficients are overall stable. Values are close to those of the optimal solution. Average gradient value is larger than optimal solution's (indicating a steep function around the solution value).
bL .750 b1 .150 b2 .125 bk .80 brk .80 br .580 bLk .080 bLr 1.50	0.3492808E-03	BL 0.21694 B1 2.1533 B2 0.39870 BK -1.5164 BR -0.86858E-01 A1 -0.42085 A2 0.31960 A3 1.4040 D1 -0.78578 D2 0.67957 D3 0.96498 D4 0.44874E-01	Coefficients are stable. Values are close to those of the optimal solution. Average gradient value is larger than optimal solution's (indicating a steep function around the solution value).
bL .50 b1 -.150 b2 .125 bk .80 brk .80 br .280 bLk .080 bLr 1.50	0.4544496E-02	BL 0.22646 B1 2.1083 B2 0.36604 BK -1.4530 BR -0.88588E-01 A1 -0.22184 A2 0.33177 A3 1.3574 D1 -0.88676 D2 0.71582 D3 0.92962 D4 0.54680E-01	Coefficients are overall stable. Values are close to those of the optimal solution. Average gradient value is much larger than optimal solution's (indicating a steep function around the solution value).

Model Estimation Results

Overall, the model fits the data well, as indicated by the overall small standard error values (in Table 2 below) and the high R^2 values (in Table 4 below). However, obtaining high R^2 values is not uncommon in time series models, due to common trends in the sample. Therefore, caution is recommended in interpreting R^2 results. This is possible by relying on additional tests of significance as performed in this section. In addition, since R^2 is computed as the ratio of the explained to unexplained variation of the dependent variable with respect to the independent variables, it follows that adding additional independent variables will increase the R^2 value (and, hence, the goodness of fit.) Thus, in order to avoid the pitfall of adding too many regressors, or independent variables, adjusting the R^2 value for the degrees of freedom is necessary. Most software packages report the adjusted values of R^2, as reported in Table 5 below.

Hypothesis tests of single parameters utilizes the familiar t-statistic test. This test is simply the estimated coefficient value divided by its standard error. It is often sufficient to report the standard errors only, as we do in Table 2 of this chapter. In the case of hypothesis testing involving multi-parameter sets, one must utilize an F-test. An F-test is simply the numerator and denominator of R^2 divided by their respective degrees of freedom. Should this ratio exceed a certain critical value, then the explained variation exceeds the unexplained variation and the variables are said to be collectively significant.

When the model is non-linear, as in this case, the F-test is not the appropriate test procedure. Instead, one must utilize one of three asymptotically equivalent tests: the Likelihood Ratio (LR) test, the Wald test, or the Lagrange Multiplier (LM) test. I apply the second test. The Wald test centers around the following argument[17]: if the restriction g (ß)=0 is true, then g (ß ^{MLE}), the maximum likelihood estimate of ß, should not be significantly different from zero. The Wald test tests whether ß ^{MLE} (the unrestricted estimate of ß) violates the restriction by a significant amount.

The Wald test has a Chi-Square distribution, and so computed values are compared to the critical values of a Chi-Square table. The degrees of freedom for this test are the number of restrictions. Results of the overall significance tests of every equation are reported in Table 3 below. There are high Wald Chi-Square statistic values for all equations and low P-values. All equations are significant, as seen by the significantly high Wald Chi-Square values. The Wald Chi-Square statistic values of all the significant equations exceed their corresponding critical values, thereby refuting their respective null hypotheses of zero coefficients. The low P-values lend additional support to the overall significance of the equations. The model was tested for autocorrelation using the standard Durbin-Watson test. All equations showed evidence of autocorrelation. Numerous attempts at correcting for autocorrelation using the standard iterative method of Cochrane and Orcutt were unsuccessful. Other attempts to correct for autocorrelation using alternate methods, such as pre-assigning a single rho value for all equations or allowing for various values of rho to be chosen at

[17] Kennedy, p. 58.

random by the estimation algorithm, have been unsuccessful as well. As a last resort, the model was treated for autocorrelation using the method of first differences, as described above.

The presence of interactive terms changes the approach of hypothesis testing, since the scope of testing spans beyond a single variable. Thus, when one attempts to test the significance of particular variable, one is additionally testing the significance of *all* the interactive terms involving that variable. Therefore, a more appropriate test of significance of such variable is the F test rather than the t test. In this case, the null hypothesis is that the coefficient value of a given variable as well as those of all the interactive terms involving that variable are jointly equal to zero. In the case of single linear restriction tests, an F test is equivalent to a Chi-Square test. Results of the Chi-Square are reported in Table 4 below.

The tests show that overall the model's variables are statistically significant from zero. In particular, physical capital, toll output, wages, and the fiber optic deployment variables are statistically significant at the 95% level. Local output and the R&D capital variables are statistically significantly at the 90%. The modern switch variable is marginally significant at the 90% level. The regulation variable was found to be insignificant even at the 90% level. However, when it is purged of its wage interactive term, it was found to be significant at the 90% level. Its P-value improved as well. The P-values for all variables also indicate corresponding significance, taking into account the adjustment in the regulation variable.

Table 2

COEFFICIENT	COEFFICIENT VALUE	ST. ERROR
BL	0.27320	0.41643
B1	2.0201	1.4071
B2	0.42450	0.15330
BK	-1.4656	0.86330
BR	-0.065626	0.20265
BLL	0.084129	0.12203
B11	0.30650	0.14165
B22	0.027483	0.028689
B12	0.086953	0.037258
BKK	-1.0355	2.2974
BRR	0.009797	0.42483
BRK	4.9904	5.9280
G1	-0.034369	0.039526
G2	0.012755	0.024441
Z1	0.018150	0.011432
Z2	0.005085	0.003635
Z11	-0.37977	0.31517
Z22	0.17823	0.056553
GC	-0.34119	0.16826
G1W	0.008400	0.013522
GYA	-0.003371	0.003805
Z1W	-0.060564	0.034814
Z2W	-0.028357	0.011946
BL1	-0.060234	0.074742
BL2	-0.025062	0.030343
BLR	0.091277	0.038045
BLK	0.10583	0.097350
BK1	-0.53334	0.21365
BK2	-0.12902	0.054531
BR1	0.031621	0.035268
BR2	-0.015976	0.012168
Demand Equations		
A1	-0.45971	0.08186
A2	0.21161	0.30462
A3	1.4786	0.19238
D1	-0.77293	0.05659
D2	0.64911	0.10163
D3	1.0178	0.18244
D4	0.04570	0.01927

Table 3

Tests of Overall Equation Significance

```
Local Demand Equation

WALD CHI-SQUARE STATISTIC = 18867.053   WITH   3 D.F.  P-VALUE= 0.00000
UPPER BOUND ON P-VALUE BY CHEBYCHEV INEQUALITY = 0.00016
```

```
Toll Demand Equation

WALD CHI-SQUARE STATISTIC =  116455.15   WITH   4 D.F.  P-VALUE= 0.00000
UPPER BOUND ON P-VALUE BY CHEBYCHEV INEQUALITY = 0.00003
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Cost Equation

WALD CHI-SQUARE STATISTIC = 15991.194   WITH   31 D.F.  P-VALUE= 0.00000
UPPER BOUND ON P-VALUE BY CHEBYCHEV INEQUALITY = 0.00194
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Local Revenue Equation

WALD CHI-SQUARE STATISTIC =  6435.6314   WITH   9 D.F.  P-VALUE= 0.00000
UPPER BOUND ON P-VALUE BY CHEBYCHEV INEQUALITY = 0.00140
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Toll Revenue Equation

WALD CHI-SQUARE STATISTIC =  79.519980   WITH   9 D.F.  P-VALUE= 0.00000
UPPER BOUND ON P-VALUE BY CHEBYCHEV INEQUALITY = 0.11318
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Share of Labor Equation

WALD CHI-SQUARE STATISTIC =  44.458034   WITH   8 D.F.  P-VALUE= 0.00000
UPPER BOUND ON P-VALUE BY CHEBYCHEV INEQUALITY = 0.17994
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Table 4 - Tests of Variable Significance

Capital Variables WALD CHI-SQUARE STATISTIC = 36.833143 WITH 9 D.F. P-VALUE= 0.00003 UPPER BOUND ON P-VALUE BY CHEBYCHEV INEQUALITY = 0.24435
R&D Variables WALD CHI-SQUARE STATISTIC = 16.442554 WITH 9 D.F. P-VALUE= 0.05820 UPPER BOUND ON P-VALUE BY CHEBYCHEV INEQUALITY = 0.54736
Local Output Variables WALD CHI-SQUARE STATISTIC = 15.061837 WITH 9 D.F. P-VALUE= 0.08925 UPPER BOUND ON P-VALUE BY CHEBYCHEV INEQUALITY = 0.59754
Toll Output Variables WALD CHI-SQUARE STATISTIC = 17.437017 WITH 9 D.F. P-VALUE= 0.04230 UPPER BOUND ON P-VALUE BY CHEBYCHEV INEQUALITY = 0.51614
Regulation Variables WALD CHI-SQUARE STATISTIC = 6.5575813 WITH 4 D.F. P-VALUE= 0.16120 UPPER BOUND ON P-VALUE BY CHEBYCHEV INEQUALITY = 0.60998
Modern Switch Variables WALD CHI-SQUARE STATISTIC = 7.1057426 WITH 4 D.F. P-VALUE= 0.13040 UPPER BOUND ON P-VALUE BY CHEBYCHEV INEQUALITY = 0.56292
Fiber Optic Deployment Variables WALD CHI-SQUARE STATISTIC = 17.318910 WITH 4 D.F. P-VALUE= 0.00168 UPPER BOUND ON P-VALUE BY CHEBYCHEV INEQUALITY = 0.23096
Wage Variables WALD CHI-SQUARE STATISTIC = 327.22473 WITH 9 D.F. P-VALUE= 0.00000 UPPER BOUND ON P-VALUE BY CHEBYCHEV INEQUALITY = 0.02750

If collinearity is present, as is the case in this model especially between interactive and non-interactive terms, the standard errors of the coefficient estimates will be large. However, the coefficient estimates will still be unbiased. As a result, the power of hypothesis testing will be low. One remedy, as mentioned above, is to limit the number of some interactive terms, or to increase the sample size. I have applied both options, first by experimenting with various combinations and numbers of interactive terms, and then by increasing sample size from thirty points to forty. Further discussion on these attempts is found in the Alternative Models chapter.

Another important question to consider is whether or not the inclusion of dummy variables is necessary. There is no doubt that the inclusion of dummy variables could add explanatory power, but there is always the drawback of losing degrees of freedom. In this model, I have attempted the limit the number of dummy variables by combining the FTA variable with the regulation variable. I have also experimented with deleting the divestiture variable altogether, since the focus of most practitioners and regulators has shifted away from that topic and more towards deregulation and alternative forms of regulation. Results, however, were not sensitive to the deletion of that dummy variable. Only if adjusted R^2 rises should an extra variable be considered for inclusion in a set of independent variables.

Output Demand Elasticities

The Nadiri and Nandi study finds the short-run average price elasticity of demand for the period examined to be -0.34 for local calls and -0.81 for toll calls.

They find the short-run average income elasticity of demand to be 0.1840 for local calls and 0.6607 for toll calls. The corresponding results of my model (Table 2) are consistent with their study and with other empirical studies. The model produces a price elasticity of demand for local service of -0.45 and a price elasticity of -0.77 for toll service. Local exchange telephone service has traditionally been perceived as a necessity; hence, it has always exhibited a smaller elasticity of demand. Toll service, on the other hand, has been perceived as more of a discretionary service, at least by most residential customers. Hence, the price elasticity of toll service is typically higher than that for local service.

Considering that access to local telephone service typically involves a flat monthly fee which entitles the subscriber to unlimited local calling, the demand for local service is not highly sensitive to changes in income. This is in contrast to toll service, which is typically measured per minute, for which the level of income is a significant factor. Thus, as expected, the income elasticity for toll service (0.64) is found to be is higher than that for local service (0.21).

The elasticities of demand with respect to number of lines have the expected signs. The local output demand elasticity with respect to the number of lines is 1.4, which indicates that as the number of lines increases by 10%, the number of calls increases by 14% (10.01% for toll service). These values are incidentally higher than those in the Nadiri and Nandi study (0.62 and 0.41, respectively). I attribute the difference to the fact that my measure is of the number of *lines*, whereas Nadiri and

Nandi's is of the number of phones [18]. The elasticity between the number of calls and the number of phones is likely to be smaller than that of the number of lines. This is because additional phones, per se, may be more of a response to the demands of convenience, space allocation, or simple luxury, as opposed to increased usage calls.

Regarding the role of wireless telecommunications services with respect to traditional (land-wire) toll services, estimation results show a positive cross elasticity of 0.0457. This indicates substitutability of wireless services for traditional toll services. This finding is consistent with the remarkable increase and widespread use of wireless communication services in the U. S. in the last two decades. According to a study by the Cellular Telecommunications & Internet Association[19], the number of wireless telephone subscribers in the U. S. rose from 91,600 subscribers in 1984 to 86,047,003 in 1999. The degree of substitutability indicated by my model, however, is not considerable. Results show that a 10% increase in the price per call of wireless services leads to an increase in the number of traditional toll calls of only 0.45%.

Economies of Scale

Economies of scale are said to exist if the average cost of production decreases as output expands. Computationally, economies of scale for a total cost function are equal to the inverse of the cost-output elasticity. In the case of a translog variable cost

[18] Considering that the Nadiri and Nandi sample begins in 1950, early data collected by the FCC consisted of the actual number of phones per household or location.
[19] CTIA, in the FCC Releases Study on Telephone Trends, p. 12-4.

function in the form of the Nadiri and Nandi model, the measure of economies of scale, ES, is:

$$ES = [1 - (\partial \ln VC / \partial \ln K_t)] / (\partial \ln VC / \partial \ln Q_i),$$

where VC is variable cost, K_t is the quantity of fixed inputs, Q_i is outputs. In the case in which the VC function includes direct measures of technology, as in this research, the ES becomes:

$$ES = [1 - (\partial \ln VC / \partial \ln K_t + \partial \ln VC / \partial Tech_t)] / (\partial \ln VC / \partial \ln Q_i),$$

where $Tech_t$ are the technology variables. These added adjustments are necessary, as pointed out by Fuss and Waverman (1977)[20], in order to account for capacity utilization and technological change. They argue that failing to correct for changes in capacity utilization of capital can be problematic for the measurement of economies of scale. They contend that if the utilization rate of capital fell consistently throughout a sample period, the inability to account for this fact would bias the measure of scale elasticity upward. This particular situation could arise when capital formation involves lumpy expenditures over increasing units of output, as is often the case in the telecommunications industry. In addition to this adjustment, Fuss and Waverman point out that the omission of some sources of technical change could also bias the scale elasticity measure upward by attributing to scale expansions in output that are

[20] Fuss and Waverman (1977), pp. 299-300.

due to technological change. Therefore, my definition of the scale elasticity includes an added adjustment (to the Nadiri and Nandi model), in order to account for technological change. As such, I deduct the elasticities of cost with respect to the technology variables from the measure of scale elasticity.

It is also possible to compute output-specific economies of scale. Such economies of scale would result from a less-than proportional increase in the cost which is specific to an output when the level of that output increases, holding all other outputs constant. Data for this measure was not available, considering the need to locate cost-specific information (or suggested weights) for intraLATA toll output, capital and R&D. This data is typically grouped with local exchange data under the total statistics of a local exchange company. In my model, intraLATA toll output is included with toll data. For single-output firms, the presence of economies of scale is sufficient to produce cost subadditivity. For multi-output firms, on the other hand, cost subadditivity requires the presence of economies of scope as well.

As stated earlier, the lack of local-output specific cost data and toll-output specific cost data for the entire sample makes it impossible to estimate output-specific economies of scale. However, conclusions can be drawn from the coefficients of the squared value of the outputs. These values indicate the rate of growth of the respective variable cost. I find that both coefficients are positive, which indicates that variable cost is an increasing function of usage (scale). This, therefore, indicates diseconomies of scale for each output. However, neither coefficient is statistically significant. Incidentally, local and toll outputs are complements, though not strong complements (B_{12} =0.86953E-01).

Table 5.1

Scale Elasticity	
1960-1964	0.8652
1965-1969	0.9102
1970-1974	0.8452
1975-1979	0.8520
1980-1984	0.7252
1985-1989	1.084
1990-1994	1.296
1995-1999	1.408
Average	0.998

The Nadiri and Nandi study finds the average scale elasticity of local and toll outputs equal to 1.1593, which indicates increasing returns to scale. In my model, as reported in Table 5.1 above, the average elasticity for the entire sample period is 0.998, which almost indicates constant returns to scale. The average scale elasticity for the period comparable to the Nadiri and Nandi study (1960-1989) is 0.879, which indicates decreasing returns to scale. This result is consistent with Evans and Heckman, Shin and Ying, and Zhou. I attribute this difference to two factors: (1) the added adjustment for technological change in my scale elasticity estimate, and (2) the hedonic nature of my cost function. Failing to account for this adjustment indeed leads to a higher measure of elasticity, though (in this case) to a modest degree. This is due to the fact that, as shown below, the elasticities of cost with respect to technology are typically small.

As for the hedonic aspect of my cost function, as pointed out earlier, my representation of cost includes direct measures of telecommunications technology. These measures arguably capture the effects of technological change in a more realistic manner than a simple time trend. Moreover, it has been shown by Spady and Friedlaender (1978)[21] that failure to account for hedonic characteristics in cost functions creates serious specification errors which lead to different inference results for economies of scale. They find that the non-hedonic cost function in their study shows a high degree of economies of scale, whereas the hedonic version shows the a mild degree of diseconomies of scale.

Taking a look at the performance of this elasticity over the entire sample, we observe a shift in the economies of scale whereby it surpasses unity in the last three sub-periods. Evidence of economies of scale in the telecommunications industry is not uncommon, particularly for the 1970's and 1980's[22]. Recent U. S. studies for the 1990's (especially through 1999) are few; however I cite, for example, a study by C. Vaz (1996), in which he finds evidence of economies of scale for the Indiana Bell Telephone Company for the entire period of 1984-1991. He attributes differences in

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[21] Spady and Friedlaender (1978), pp. 159 and 171.

[22] See for example Christensen, Christensen, and Schoech (1981), Nadiri and Schankerman (1981), Nadiri and Nandi (1997).

economies of scale results to the choice of an appropriate proxy for technological change, to aggregation issues, and the use of accounting costs versus economic costs.

The shift in economies of scale in my model may be attributed to: (1) a slow loss of market share by established companies, (2) mergers and acquisitions among telecommunications firms which have expanded the scale of operations, (3) an increase in the growth rate of R&D expenditures, and (4) significant cost-saving effects of fiber optic deployment. I address each factor in detail below.

Looking at the third-to-last sub-period, it is observed that economies of scale increased immediately following the AT&T divestiture (1984) from 0.7252 to 1.084. This result is surprising since the main goal of divestiture was to "break up a monopoly". But taking a closer look at the smaller picture reveals additional factors at play. Considering that the collective market share (reflective of the scale of operation) of the old Bell System in the local exchange market was inevitably divided up following divestiture, the respective market shares of the post-divestiture Bell companies' newly-delineated markets still remained, by any definition, considerable. And though AT&T's share of toll revenues, which was 90.1% before divestiture, began to gradually erode following divestiture, it still managed to command a significant size of the U. S. toll market by the end of the decade (67.5% in 1989). The new Bell System also maintained respective ownership of a considerable portion of the nations' physical telecommunications network. In the meantime, independent LECs also maintained their market shares, by virtue of their existing franchise rights, while venturing into new rural areas aided by their earlier investments into advanced switching and transmission technologies. Thus, the trend of sustained, even increased, economies of scale is not surprising.

Turning next to the performance of the scale elasticity in the last decade of the sample, we note an increase in its value from 1.08 to 1.40 by 1999. This is probably contrary to most expectations, especially in the regulatory circles. The deregulation efforts of the 1990s, especially the Federal Telecommunications Act of 1996, were meant to facilitate competition, break the concept of natural monopolies and limit the market power of large established carriers. This was expected to occur partly through direct legal means, such as lifting market entry barriers, and requiring interconnection and resale of facilities, and partly through market means, such as the probable loss of market share due to the increased number of competitors. There was also a reliance on the positive effects of new production techniques which may be less cumbersome and not quite as large scaled as earlier versions. What has occurred instead, which I believe lends an explanation to this outcome, is a trend of mergers and acquisitions in the telecommunications industry.

The trend began in the early 1990s and accelerated in the mid to late 1990s following the 1996 implementation of the FTA. Of significance is the Southwestern Bell/Ameritech merger (now called SBC), the Bell Atlantic/GTE merger, coupled with NYNEX Corporation (now collectively called Verison), and the Qwest/US West merger (now called Qwest). The only Bell company still operating independently today is Bell South, which still commands a huge customer base of almost 20 million customers. This trend in mergers may be viewed as a "defensive" measure, taken particularly by established carriers for fear of loss of customer base and market share. The outcome has lead to the preservation of the established firms' scale of operation. This, in turn, has preserved the associated positive returns to scale. These corporate changes have significantly expanded the size of these telecommunications firms contrary to the intentions of the Federal Telecommunications Act and despite the emergence of new competitors in the market. It leaves something to be said of the old saying "if you can't beat them, join them". Some have argued that the FTA has had the unintended effect of reversing the achievements of the AT&T divestiture. It is probably premature at this point form an assessment, but early indications seem to lend support to the argument.

The increase in economies of scale is also attributed to the significant increase in telecommunications R&D expenditures in the 1990's, which was part of an overall national trend. According to the National Science Foundation[23], the increase in R&D expenditures between 1994 and 2000 was the greatest single real increase (approximately 6% annually) for any six-year period in the history of R&D data (since 1953). My data shows that R&D expenditures in the telecommunications industry have indeed increased overall since the 1998's, despite fluctuating changes from year to year. The elasticity of R&D expenditures with respect to cost (see Table 5.5 below) is approximately –0.30 for the last decade of the sample.

[23] The National Science Foundation, Division of Science Resources Studied, Data Brief, NSF 01-310, November 29, 2000.

Another factor for the shift in economies of scale in the last decade is a 30% increase in the elasticity of physical capital with respect to cost in the last decade to around -1.7. I attribute this increase in part to the cost savings effects of fiber deployment, which in turn depend on my depiction of this technology in the model. Fiber deployment, as explained below, is a method of telecommunications transmission. As such, it is an improvement or an advancement over previous transmission methods. One could therefore depict this technology as a continuum over time. However, due to variations in the industry's definitions of data measurement, inconsistencies in published data, and different regulatory reporting requirements, it is difficult, if not impossible, to arrive at a complete and consistent sample depicting telecommunications transmission techniques over time. Therefore, I resorted to depicting fiber deployment as a "snap shot in time", meaning as a brand-new technology in and of itself. This required some smoothing of the data, but only as far as four sample points in the early 1980's. The effect of this approach has lead to a shift in the effects of technology toward the end of the sample through the higher elasticities of physical capital.

Cross Subsidization

Cross subsidization in telecommunications is an interesting phenomenon. While theoretically undesirable, it has long been allowed in practice. The practice by telecommunications firms of inflating business rates in order to maintain residential rates at an affordable level has been defended by regulators as a means for guaranteeing universal service for all citizens. In addition, cross subsidization between local and toll rates, whereby the later subsidize the former, has long been advocated as an additional means of ensuring the affordability of local residential rates. This is because business customers tend to make more toll calls, on average, than residential customers. Furthermore, since business customers tend to be located in urban areas, the combined effect of both types of subsidies is to provide support to rural customers. Rate averaging, per se, between rural and urban areas also ensures affordable rates to rural customers.

On theoretical grounds, cross subsidization has been criticized for its lack of economic efficiency. Alfred Khan[24], in particular, has been a strong opponent of cross subsidization. He advocates adopting an efficient pricing system which closely reflects marginal costs. Though Khan has offered numerous arguments in favor of economic efficiency, equity, and competition, regulators have generally been reluctant to adopt his recommendations. The likely reason for this is the regulators concern that adopting a more efficient pricing system may have serious adverse political consequences.

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[24] Khan, Alfred, The Road to More Intelligent Telephone Pricing.

Concern about cross subsidization was likely one of the reasons for the AT&T divestiture. Toll prices were relatively high, or at least non-decreasing[25], considering efficiency gains stemming from new advancements in technology. By separating the toll and local components of the Bell System operations, regulators hoped to eliminate the mechanism which facilitated this practice. However, a new form of cross subsidization quickly took place and that is access charges. Access charges, paid per minute by toll providers for the use of the local exchange networks, were disproportionately high considering the increased use of toll calling over the last decades[26].

Currently, the view on cross subsidization is changing. With the enactment of the Federal Telecommunications Act (FTA) of 1996 and the subsequent introduction of competition in the local exchange market, state regulators were forced to re-consider the validity, much less the practicality, of this practice. At the very least, some have approached the notion of eliminating the practice of cross subsidization gradually by implementing *temporary* caps (or rate increase moratoriums) on basic local exchange rates until such time as local competition has effectively materialized. Others have attempted to seek more explicit mechanisms of supporting rural rates, by implementing, for instance, so-called "high-cost funds". These funds are supported by

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[25] Data show that average toll rates (measured per call) continuously increased from 1960 through 1983. Since divestiture, they have been steadily decreasing.

[26] Access rates have fallen considerably since 1996. The per minute rate decreased from $.06 in 1996 to $.03 in 1999.

rate payers for the purpose of compensating local service providers for the high cost of providing telephone service in rural areas[27].

Table 5.2

Cost Elasticity With Respect to Local Service		Cost Elasticity With Respect to Toll Service	
1960-1964	1.996	1960-1964	0.410
1965-1969	1.999	1965-1969	0.416
1970-1974	1.997	1970-1974	0.422
1975-1979	2.000	1975-1979	0.420
1980-1984	2.100	1980-1984	0.425
1985-1989	1.999	1985-1990	0.423
1990-1994	2.000	1991-1994	0.420
1995-1999	2.002	1995-1999	0.421
Average	1.999	Average	0.4210

In order to empirically analyze the notion of cross-subsidization in this model, a distinction must be made between pre-divestiture and post-divestiture results. Analysis must also be confined to cross-subsidization between local and toll services, as no other aspects of cross-subsidization are available through this data. Looking at Table 5.2 above and starting with the pre-divestiture (up to 1984) results, the average price mark up[28] for local service is 2.046, while it is 8.6 for toll service. Looking at the corresponding period in Table 5.2 above, the cost elasticity of local service is approximately 2.0, while it is approximately 0.40 for toll service. Therefore, there is evidence of pre-divestiture cross subsidization between local and toll services. This is

[27] SEC 254 of the Federal Telecommunications Act of 1996.
[28] Price mark-up is measured as Output Price-Unit Incremental Cost / Unit Incremental Cost.

reflected in the divergence between the cost elasticities with respect to each output, versus the disproportionate divergence between their respective prices. In other words, output prices of toll service (having a large average markup of 8.6) are disproportionate to their cost elasticities (having an average of only 0.42), while output prices of local service (having an average markup of only 2.0) are disproportionate to their cost elasticities (having an average of almost 2.0, or 1.60 higher than toll's). Thus, toll prices appear to be subsidizing local prices.

Looking at post-divestiture results, there is a remarkable decrease in the price-markups for both outputs. The price markup for local service decreased from 1.56 (as of 1984) to 1.03 (as of 1989) and down to 0.98 by the end of 1999. The price markup for toll service decreased from 8.11 (as of 1984) to 1.79 (as of 1989) and down to 0.83 by the end of 1999. It can safely be inferred that these results lend support to the conclusion that the AT&T divestiture has succeeded in eliminating the practice of cross-subsidization between toll and local services. Though discrepancies still exist between the price markups and their respective cost elasticities, these discrepancies cannot be attributed to cross subsidization, since the corporate linkage between their sources of production has been severed. Looking at the markups of these services is meaningful only in terms of their corresponding costs with appropriate implications, as done in the section on competition.

The various effects on the cost elasticities with respect to local and toll outputs are seen by decomposing the expressions. The cost elasticity with respect to local output is:

$$b_1 + b_{11}\ LY1 + b_{12}\ LY2 + g_{Ya}\ REG + b_{L1}\ LW + b_{k1}\ LK + b_{r1}\ LRD + Z_1\ LMod + Z_2\ LFib$$

All coefficients in the above equation are positive, except for the physical capital coefficient, b_{k1} (-0.53334), the wage rate coefficient, b_{L1} (-0.060234), and the regulation coefficient, g_{Ya} (-0.0033711). Therefore, in spite of the cost-reducing aspects of the production process of local service, other factors have acted in the opposite direction. These factors are R&D expenses, technology expenses, the complementary cross elasticity between local and toll services, and the increasing rate of local output growth. The overall effect, as stated above, is a positive cost elasticity with respect to local output.

The cost elasticity with respect to toll output is :

$$B_2 + b_{22}\ LY2 + b_{12}\ LY2 + g_{Ya}\ REG + B_{L2}\ LW + b_{k2}\ LK + b_{r2}\ LRD + Z_1\ LMod + Z_2\ LFib$$

Five coefficients (B_2, B_{12}, Z_1, Z_2, and B_{22}) are positive, which leads to the overall positive value of the expression. The remaining coefficients (B_{L2}, B_{K2}, B_{R2}, and g_{Ya}) though negative; do not have a strong enough counter effect to cause a negative elasticity. Therefore, the cost-saving aspects of toll production are wages, capital and R&D expenses, and deregulation. While R&D expenses have a cost-saving effect on the production of toll output, they do not have a similar effect on the production of local output. This is likely due to the fact that most of the local service R&D expenditures have been geared toward product-oriented goals, such as better and multiple calling features (e.g., caller ID, call forwarding and three-way calling). Product-oriented goals tend to have delayed and indirect monetary gains. This is in contrast to process-oriented goals for toll service R&D expenses, such as toll service over microwave, wireless or fiber optic lines.

Regulation

One goal of this research is to measure the effects of changes in regulation on the market structure of the telecommunications industry. In my model, I have represented regulation by two variables: a dummy variable, DIV, for the effects of the 1984 AT&T divestiture and an explanatory variable, REG, for the collective effects of state and federal rules and regulations in the post divestiture era. The divestiture variable is modeled singularly (or neutrally) with no interactive terms. The REG variable is modeled interactively with every explanatory variable in the cost equation. The REG variable is designed to capture any and all aspects of regulation, including full regulation, deregulation, and alternative regulation[29].

[29] Alternative regulation refers to regulatory plans other than rate-of-return regulation. The details of alternative regulation have been already discussed in Appendix 1.

Table 5.3

Cost Elasticity With Respect to Regulation	
1960-1964	-0.10736
1965-1969	-0.09427
1970-1974	-0.11022
1975-1979	-0.10840
1980-1984	-0.14476
1985-1989	-0. 065160
1991-1994	-0.04428
1995-1999	-0.05694
Average	-. 091415

Looking at the empirical results of the model, the effect of divestiture is an overall cost increase of 0.091%, however this effect was found to be statistically insignificant. The Nadiri and Nandi study finds the overall effect of divestiture to be a yearly reduction in variable cost of 2.63%. This difference is attributed to their measure containing interactive terms. I elected to de-emphasize the role of divestiture in my model, due to limitations on the number of available degrees of freedom and due to my focus on more recent regulatory changes. The Cost Elasticity with respect to regulation is equal to:

$$g_l + g_c (LK + LRD) + g_{Ya}(LY1 + LY2) + g_{lw} LW$$

The coefficient values in this equation are each negative, except for the last coefficient. This last coefficient (of the effect of regulation on wages), however, as pointed out earlier does not contribute meaningfully to the statistical significance of this variable. Turning to the summarized results of the regulation variable in Table 5.3, the average effect of deregulation on variable cost is negative (-0.091415) for the sample period. This is to be expected and is consistent with Zhou's finding that LECs subject to price cap regulation have a 3.3% lower costs (a price cap regulation dummy coefficient value of -0.067) of than those under rate of return regulation. By 1991, significant changes had occurred on the state regulatory front towards relaxed and alternative regulation. For example, by 1991, only five states had full regulation of interLATA services and thirty states had allowed for competitive entry in the intraLATA market[30]. Deregulation can be cost saving, as it reduces the frequency of rate reviews, the number of case filings, the extent and frequency of court litigation, and the level of reporting requirements. It may also contribute to a reduction in the risk of investment, as deregulated (or unregulated) firms do not have to be concerned with the effects of the regulatory body's next move on their business activity.

Curiously enough, the value of this elasticity has decreased in the last ten years of the sample. This is attributed to the emergence of new types of regulation-induced costs, such as those related to network interconnection, network collocation, new performance standards, and new litigation and compliance costs brought about by the Federal Telecommunications Act of 1996. At first glance, this decrease in the elasticity value may be thought to be attributed to the notion that the Averch-Johnson effect of rate-of-return regulation (RORR) may sometimes manifest itself in a

[30] Flannery (1996), p. 40.

resistance by the regulated firm to engage in capital-saving investments[31]. The argument is that profit incentives under RORR, and possibly price regulation, are often not sufficient for optimal investment. Under RORR (i.e., average cost pricing), the regulated firm does not earn economic profits (at least not in the long run). Therefore, investing in capital-saving activities may not be in its long-term best interest. Under price cap regulation, the firm's profits are also constrained by the level of the price cap. There are also added uncertainties related to future costs and future output demand. These factors may curtail the firm's incentive to invest in cost-saving capital equipment. But I find evidence to the contrary. Empirical results of investment patterns indicate that capital investments have yielded significant cost savings (see Table 5.5 below), as has R&D investment (since divestiture).

Technology

Telecommunications Technology

There are three main categories of telecommunications equipment: (1) customer premises equipment; (2) switching equipment; and (3) transmission equipment. Customer premises equipment consists of handsets, fax machines, modems and private branch exchanges (PBXs) located on the customer's premises. Switching equipment connects calls within and between central offices. Transmission

[31] Khan (1988).

equipment transmit calls from the central offices to the customer premises. It consists of twisted copper pair wires, coaxial cable, microwave, radio and fiber. My research focuses on switching equipment and fiber transmission equipment.

Telephone switches are an integral part of a telecommunications network. A switch is located in a central office or wire center. The main function of a switch is to connect calls within the same switch or to another switch through an interoffice trunk. There may be more than one switch per central office. The first switches were manual switchboards, followed by step-by-step switches which were invented in 1892, and then cross-bar dial switches and panel dial switches.

Until the 1960s, switches were automatic electro-mechanical. They required exclusive paths between callers who are located in different exchanges, and therefore were distant-sensitive and traffic-sensitive. Their capacity was also dependent upon the volume of traffic and the duration of calls. In 1965, Analog Stored Program Control (SPC) switches were introduced. They had the capability to handle calls and process call features through a computer program. They were faster, more compact, and more reliable. However, they still relied on analog technology in transmitting voice messages and they required exclusive circuits between callers.

With digital technology came the introduction of the first digital switch in 1976. Voice and data messages can now be transformed into digital signals, which are electronically compressed and intermittently transmitted as packets. Calls did not require exclusive paths and could travel simultaneously in shared networks. Digital switches, along with a new computer software called Signalling System 7 (SS7), made it possible to provide a variety of new services, such as voice mail, teleconferencing, credit card authorization and electronic funds transfers. In addition, they made the provision of equal access among different carriers more efficient.

Fiber optic technology began in 1977. Fiber optics is a method for the transmission of voice, video and data in which light is modulated and transmitted over hair-thin filaments of glass. It has tremendous speed and capabilities. In 1989, a fiber optic pair carried less than 20 billion bits per pair; while in 1999, it carried 160 billion bits. Translated into phone calls, this means 24,000 simultaneous calls in 1989, compared to 8 million calls in 1999[32].

Although transmission over copper wires continues, and has actually increased by about 15% from 1991 to 1998[33], transmission by fiber has increased over five times. Analog links have virtually disappeared, and the number of interoffice fiber carrier links has surpassed the number of copper carrier links. Technically speaking, circuits connecting central offices can be provided over two fibers only. Practically speaking, these circuits are typically provided over 40 fibers[34]. This may imply excess fiber capacity.

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[32] Telecommunications Research and Associates (TRA), 1998, Understanding the Basics of Communications Networks, St. Marys, KS, p. .

[33] Federal Communication Commission, Infrastructure of the Local Operating Companies, July 1999, p. 5.

[34] Ibid., p. 5 .

Depending upon construction, fiber can be classified as either single mode fiber (SMF) or multi-mode fiber. SMF has a core diameter of 8.3 to 10 microns. Its bandwidth is limited by the speed of the transmitting and receiving electronics, not by the bandwidth of the fiber. Essentially, all telecommunications carriers as of 1999 used single mode fiber in their networks. Multi-mode fiber is larger than single-mode fiber, and thus it permits transmission in multiple paths. Multi-mode fiber is able to use light emitting diodes (or LEDs) to generate light pulses which are inexpensive compared to the lasers used in SMF systems. Because of its lower cost and its lesser susceptibility to damage from bending, it is popular for use in customer premises[35].

From a cost standpoint, the provision of outside plant telecommunications facilities, such as switches and fiber optic cable, consists of fixed and variable cost components. The fixed component of switching is operation and maintenance. The fixed component of fiber optics consists mainly of the labor cost of placing cable wires underground and of the cost of multiplexers. The variable component relates mainly to the maintenance of the cable and is positively correlated with the number of wire pairs within the cable. Additional variable costs include interface cards and digital cross-connects.

It can further be argued that the major cost components of fiber optic deployment are huge, irreversible and non-recoverable. The cost of the cable itself

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[35] Telecommunications Research and Associates (TRA), 1998, Understanding the Basics of Communications Networks, St. Marys, KS, p. 61.

and its installation under-ground are quite expensive; and once the cable has been laid under ground, it is very difficult, if not impossible, to remove. Furthermore, there are virtually no opportunities for recovery on the investment of unused (i.e., dark or unlit) fiber. There is, of course, the possibility of selling or leasing the unlit fiber, but that only recoups part of the investment.

On the other hand, as stated above, there are considerable economies of scale to be gained from the deployment of fiber optics. A fiber optic cable transmits much more information than a traditional pair of copper wires and it contains a much wider bandwidth to carry various services. It is no wonder that the Bell operating companies have installed about 1.9 million fiber terminations by the end of 1998[36], an increase of 21% from the previous year. Fiber is expected to become increasingly important in the face of increased demand for digital services as it replaces copper wires in the local loop.

Digital switches, which constitute most of my sample data on switches, come in a variety of sizes (from 20 lines to more than 100,000 lines[37]) As such, they have reduced the economies of scale associated with telephone switches in general. Their introduction in the mid 1970s has allowed smaller firms easily to acquire them, and thus to compete more effectively with larger established firms. The price of digital.

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[36] Federal Communication Commission, FCC Releases Study on Telephone Trends, Washington, D. C., December 21, 2000, p 5.
[37] Telecommunications Research and Associates (TRA), 1998, Understanding the Basics of Communications Networks, St. Marys, KS, p. 5-8, and Zhou (1996).

according to Hausman, switches has fallen from $240 per line in 1986 to about $130 per line in 1996. The availability of additional features, such as remote maintenance and automated housekeeping and billing technologies have made it possible to centralize these functions and to overcome the need for large scales of operation.

Yet the fact remains that investment in telephone switches is largely non-recoverable. Once a telephone switch has been installed, it is difficult, if not impossible, to have it removed. Leasing it is an option, but it is highly uncommon. In addition to this largely sunk cost of acquisition and installation, there are also considerable variable costs associated with maintenance, monitoring, climate control, and security. Therefore, some may argue, as Greenwald and Sharkey (1989) do, that despite the aforementioned advancements in digital switches, large LECs still maintained the essential characteristics of a natural monopoly at least through 1988. This is attributed in their view to economies of scale and scope in the physical provision of basic services, economies of scale in network planning and management, network externalities, and advantages in raising capital. I turn to the effects of technological change next.

Estimation Results of Technology Variables

Technological change is typically measured as the derivative of cost with respect to time. However, since time cannot be used as an explicit variable in a first-differences model, I derive an alternative measure of technological change using technology variables in lieu of time. Therefore, technical change (or progress) is measured as (∂ ln C / ∂ ln Tech), where Tech is either the log of modern switches (LMod) or the log of fiber optic miles (LFib). In this model, technological change is a function of output, capital and technology:

Technical Change with Respect to Modern Switches =

$$-[Z_1 + (Z_{11}\,LMod+Z_{22}\,LFib)\,Z_{11} + Z_{1w}\,LW + Z_1\,(LY1+LY2) + Z_1\,(LK+LRD)\,]$$

Technical Change with Respect to Fiber Optic Miles =

$$-[Z_2 + (Z_{11}\,LMod+Z_{22}\,LFib)\;Z22 + Z_{2w}\,LW\; + Z2\;(LY1+LY2) + Z2\;(LK+LRD)\,]$$

Table 5.4

Technical Change w/r Modern Switches		Technical Change w/r to Fiber Deployment	
1960-1964	-0.02140	1960-1964	-0.005506
1965-1969	-0.02240	1965-1969	-0.005880
1970-1974	-0.08752	1970-1974	0.023040
1975-1979	-0.05758	1975-1979	0.000899
1980-1984	0.01954	1980-1984	-0.163670
1985-1989	0.04457	1985-1989	-0.018042
1990-1994	-0.04086	1990-1994	-0.008710
1995-1999	-0.02013	1995-1999	-0.01017

As shown in Table 6.4 above, results indicate that, until 1979, a 10% increase in the deployment of modern switches causes a 0.48% reduction in the industry's variable cost. Since 1989, that effect is approximately 0.30%. Zhou (1996) found that a 10% increase in electronic switching reduces cost by 1.2%. He uses total cost, rather than variable cost, which may account for the difference. This also indicates a reduction in fixed cost of approximately 1%, in order to arrive at the same result of this study. This is plausible considering the significant up-front cost of switch installation, which makes up a significant proportion of fixed costs. I also find a positive (cost increasing) effect of telephone switching in the decade of the 1980's. This is likely due to the fact that the gains of upgrading to digital switching, in itself costly, had not yet had their cost saving effect on cost.

It is peculiar to note that the measured effects of advanced technology in general on the cost of telecommunications are small. A likely explanation for this, as pointed out by Zhou, is that advanced technologies may be more product-oriented than process-oriented which may put upward pressure on production costs rather than lowering them. I expand upon this notion below. Also, it is possible that some LECs have been reluctant, or even resistant, over the years to the deployment of advanced technologies. It has sometimes been said by some LECs in regulatory circles that unless they were allowed to enter into new lines of business such as interexchange and cable services, investment in new and advanced technology would not be economically prudent.

As for the effect of fiber deployment on cost, results show that a 10% increase in fiber deployment causes 0.50% (1980-1999) decrease in variable cost. This can be compared to Zhou's result of 2.3% (of total cost). This is to be expected since the incremental cost of fiber deployment is typically small[38]. In addition to this fact, Zhou's measure of fiber deployment is different, as it is calculated as the percentage of deployed fiber cable *in total cables.* His measures reflects the intensity of fiber deployment for a given number of cables, while my measure reflects the overall national level of fiber cable deployment. Specifically, my measure quantifies the number of individual customer services provided over fiber strands terminated at the customer's premises, plus fiber strands terminated at the central offices. Given Zhou's smaller sample (1988-1994), and the fact that the intensity of fiber for a given number of cables is considerably high, it follows that the cost saving effects would be higher. The effect of nation-wide fiber deployment measured by the number of fiber miles per year may not be as pronounced considering the geographical scope over which fiber deployment is spread.

Effects of Technology on Product Demand

The effects of technology on the demand for local and toll services can be discerned by examining the revenue share equations. Recalling equations 1.5 and 1.6,

$$R1 = (b_1 + b_{11}\,LY1 + b_{12}\,LY2 + b_{L1}\,LW + b_{k1}\,LK + b_{r1}\,LRD + g_{Ya}\,REG + Z_1\,LMod + Z_2LFib)(1+1/a1)^{-1}$$

[38] Federal Communication Commission, Infrastructure of the Local Operating Companies, July 1999, p. 5.

$$R2 = (b_2 + b_{22}\,LY2 + b_{12}\,LY2 + b_{L2}\,LW + b_{k2}\,LK + b_r\,LRD + g_{Ya}\,REG + Z_1\,LMod + Z_2\,LFib)\,(1+1/d1)^{-1}$$

The effect of modern switch deployment on the share of local revenues is equal to:

$$Z_1\,(1+1/a1)^{-1} = -0.0155$$

The effect of fiber optic deployment on the share of local revenues is equal to:

$$Z_2\,(1+1/a1)^{-1} = -0.00434$$

The effect of modern switch deployment on the share of toll revenues is equal to:

$$Z_1\,(1+1/d1)^{-1} = -0.00526$$

The effect of fiber optic deployment on the share of toll revenues is equal to:

$$Z_2\,(1+1/d1)^{-1} = -0.003610$$

Due to technological advancements brought about by investment in capital and R&D, the cost efficiencies in the production of local service have lead to a reduction in the price of local service output. Considering that the demand for this service is inelastic, this price effect has led to a reduction in the share of local revenues (of variable cost). This reduction is equal to 1.55 % in the case of technological advancement from modern switching, and is equal to 0.434 % in the case of fiber optics.

The situation is similar in the case of toll service output. The cost efficiencies of technological advancements have lead to a reduction in the price of toll output. This has lead to a reduction in the share of toll revenues, though to a larger extent since demand for toll service is much more elastic than that for local service. This reduction in the revenue share is equal to 0.526 % in the case of technological advancement from modern switching, and 0.36 % in the case of fiber optics.

TECHNICAL BIAS

According to R. Stevenson (1980), technological change may be biased both with respect to factor inputs and the scale characteristics of the production process. With regards to factor bias, the notion of neutrality, against which we measure bias, could be regarded as a "Hicksian neutrality". This means that a shift of the production isoquant along a firm's expansion path does not alter the factor proportions or the factor shares. If there is a change in the factor proportions, then there is evidence of bias. Input bias is measured as the change in the input cost share equation(s) with respect to time.

Following Stevenson, I examine technological change bias with respect to factor inputs and scale characteristics of the production process. Again, I apply direct measures of technology in lieu of the time variable. Clearly, the measures of input bias in this case are simply the sum of the technology coefficients values (Z_{1w} and Z_{2w}) in the labor share equation. As shown above in Table 2, Z_{1w} is equal to -.06056 and Z_{2w} is equal to –.02835. A negative value of input bias means that technological change is labor-saving, while a positive value implies that it is labor-using. Since both coefficient values are negative, I conclude that labor is factor saving when it comes to the deployment of modern switches and fiber optics. This means that the labor bias of technological change for a firm operating on its output expansion path would have been to reduce its labor share from 0.273 (b_L) to 0.2124 (a reduction of 0.0605). This result is expected for the case of modern switches, but it is surprising for the case of fiber optics, since it involves considerable labor usage in the installment stages. It is possible, however, that the labor-saving aspect of fiber optics stems from the automated services that *follow* from its adoption.

Technological change may also biased with respect to returns to scale characteristics. This means that the range over which economies of scale can be realized, including the minimum efficient size (MES) of the firm, can be affected by how sensitive "or biased" technological change is with respect to the scale of operation. Returns-to-scale bias is measured as the change in the economies of scale measure with respect to time (or technology). The definition of neutrality with respect to returns to scale characteristics (against which we compare bias) is simply the case of constant returns to scale.

Assuming that the scale bias measure has the same sign over the output range, if it is less than zero, then it implies minimum efficient firm size (MES) can be attained at a higher output level. This is because as time passes by (or technology advances) in the relevant output range, the value of the economies of scale measure increases. Therefore, the MES of the firm is achieved at a higher level of output (or scale). Similarly, if the scale bias is larger than zero, then it implies MES can be attained at a lower level; and if it is equal to zero, then there is no change in MES. In this model, technical scale bias is positive (using both technology measures) which implies that the minimum efficient size of telecommunications companies can be attained at a lower output level. In other words, the telecommunications industry in general is exhibiting excess capacity and thus, the minimum efficient size (i.e., optimal size) of the firm is smaller. There is recent evidence that the telecommunications industry is suffering from excess supply (with respect to fiber optic deployment in particular), due to exaggerated expectations of demand[39]. This conclusion could alter the degree of supportable competition in the market and thus could have significant policy implications. I address these issues in the conclusions chapter.

Since a larger scale of operation may be better suited to the achievement of technological advancements, especially in a highly capital-intensive industry like telecommunications; some technological advancements are themselves conducive to larger scales of operations. In other words, a large telephone switch requiring considerable space, adjunct facilities, considerable energy use, high security, and monitored climate control, is more suited to a larger scale of operation. In that case, the rate at which costs decline over time for a given level of output may itself be a function of the scale of operation. To explore this possibility, I examine the rate of change (or second derivative) of the technological scale bias with respect to output. Since the rate of change of technical scale bias is not a function of the level of output, it is concluded that the *rate* at which costs decline over time does not depend on the

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[39] Federal Reserve Bank of Dallas, Jan/Feb 2002, p. 12.

scale of operation. In other words, even though one might argue that larger firms with larger R&D budgets are likely to be able to reduce costs at a faster rate than smaller firms, it is not my finding that the rate of decline in costs is attributed to the size of the firm. This coincides, in particular, as discussed above, with the nature of digital switch deployment. The multiple dimensions of digital switch sizes have enabled smaller firms to easily acquire them and to reap their benefits.

The Hedonic Aspects of Technology

When one speaks of technology, one is typically referring to scientific theories, methodologies, and information translated into applied procedures, machinery and equipment. Therefore, technology, in essence, consists of research and development applied into physical and human capital. Furthermore, when one describes the "level" of technology at any given point in time, one is usually referring to the attributes of goods and services (e.g., faster, smaller, stronger, quieter, etc.) created as a result of advancements in technology.

Devendra Sahal[40], in his pioneering work on the dynamics and management of technological change, identifies three types of technology: (1) a neoclassical definition in the form of a production function; (2) a Pythagorean concept defined in terms of

[40] D. Sahal, 1981, p 15.

patent statistics and chronologies of major innovations; and (3) a systems viewpoint which defines technology in terms of its functional properties. In this research, I (1) indirectly apply the first method, through the use of duality theory; (2) consider the second approach through the use of instrumental variables (discussed in the Alternative Models chapter); and (3) directly apply the third approach in conjunction with the first through my focus on the hedonic aspects of technology.

As my research attempts to show, and as put forth by Sahal, there are numerous advantages to the systems approach, which I will refer to as the hedonic approach. One advantage to the hedonic approach is that hedonic measures of technology have clearly defined meanings and can be easily measured. For example, the scope and versatility of a communication transmission line can be described by its bandwidth. A second advantage of the hedonic approach is that hedonic measures of technology have practical managerial applications. For example, the focus of R&D projects is usually on a specific function or attribute of technology, such as a faster modem or a wider broadband. A third advantage, not utilized in this model, is that hedonic measures allow for the assignment of weights to major and minor innovations.

The three approaches outlined above are not necessarily exclusive; they can and do complement one another. What the neoclassical approach lacks in the explicit measurement of technical change, it makes up for in its description of the production process. And what the hedonic approach lacks in macro applications[41], it makes up for in its micro applications. And what the two approaches lack in direct statistical compilations, the Pythagorean approach make up for in its practical representation. I will dispense of the use of the last approach, however, due to the limitations imposed by the cost function, as explained in Chapter Three.

[41] As pointed out by Sahal, the very fact that the hedonic approach to technology representation entails specific descriptive attributes of the respective technologies renders it inapplicable to inter-industry comparisons.

Turning back to the empirical model, it is noted that using direct measures of telecommunications technology, such as switches and fiber optic cable, provides additional insights into the effects of technology on the structure of production and cost. Arguably, it is more realistic to portray technology by some tangible measure of machinery or equipment rather than relying upon the passage of time as a proxy for the advancement of technology. By expressing telecommunications technology as both a specific type of machine (i.e., a modern telephone switch) and as a specific medium (i.e., fiber optic cable), the hedonic aspects of technology are explicitly acknowledged through those of the physical capital into which it is applied. The physical measures of the technology that are themselves components of the total investment in physical capital are also acknowledged. Therefore, technical progress in this research is "capital embodied", in that it consists of innovations manifested in the form of new machines. Technical progress also has an element of being "disembodied", in that also consists of improvements in the efficiency of existing and new techniques due to increased knowledge and experience.

Incidentally, my choice of technology variables, though dictated by empirical convention and industry standards, is consistent with Sahal's[42] principle of technological "guideposts". The principle postulates that the process of technological development invariably leads to a certain pattern of design. In other words, new innovations or R&D projects are often geared toward refinements of an original

[42] D. Sahal, 1981.

concept or design. A case in point is the telephone switch, which in spite of having been invented over a century ago, still retains its basic operating concepts.

Another feature of the technology variables in this research is that they do not necessarily increase in an exponential rate as time does. Rather, they are influenced in part by economic events or business cycles. This is confirmed by the oscillating patterns of the growth rates of the two technology variables in this model. Moreover, the assimilation of these technologies within the industry is not presumed to be automatic. The reason for this is that new telecommunications technologies, like most technologies, are often company-specific. In addition, most new technologies are protected by patents, which delay their assimilation in the market. This is confirmed by the delayed effects of technological advancement in this model on the cost structure of the industry.

Recalling the rate of technical change equations, it is recalled that the cost saving element in those equations is the wage component. That is, the high capital intensity of both of my choice variables of modern telecommunication switches and of fiber optic cable produces technological efficiencies reflected in less labor usage in favor of capital. Indeed, I find that the share of labor in variable cost in the U. S. telecommunications has declined considerably from 0.67 in 1960 to 0.29 in 1999. The share of physical capital, on the other hand has risen from 1.26 in 1960 to 1.38 in 1999. Moreover, the very technical nature of my two chosen components of the telecommunication network as well as their associated investment characteristics provide for the pattern of cost elasticities described above.

Investment Decisions

Investment decisions in telecommunications are affected by many factors, such as expected profitability, risk, regulation, competition, technology, macro-economic conditions, and network characteristics. Larry Darby (1997), former FCC Chief Economist and former Senior Economist of the White House Office of Telecommunications Policy, argues that most theoretical models of telecommunications investment (capital formation) are inadequate for making predictions about the effects of economics changes on the level of investment. For example, he observes that changes in interest rates no longer account significantly in changes in telecommunications stock prices. Therefore, in order to look for determinants of investment as a whole, he argues that one should investigate three sources if literature: (1) financial investment models (i.e., determinants of stock prices); (2) capital budgeting models (i.e., determinants of real investment); and (3) econometric models which attempt to explain ex-post levels of investment.

Clearly, it is beyond the scope of any one model to encompass all of the above. The resulting "laundry list" of explanatory variables would be quite extensive-as duly noted by Darby himself. However, it is possible to capture, in one model, a large proportion of these variables (explicitly or otherwise) as many models attempt to do including this model. From an investment point of view, my model includes the following determinants: expected earnings (implicitly), the discount rate (implicitly), the rate of technological change, changes in product demand, the price of capital goods, and input prices. What the model fails to take account of are estimates of risk, equipment replacement cycles, time patterns of future investment payoff streams, and the expected growth of the industry. The model, however, offers insights into investment, profit and production patterns of telecommunications companies. Furthermore, the model's scope is broadened by including the output demand side of the decision making of the companies.

Considering investment patterns, it is reported in the Nadiri and Nandi study that there is possible evidence of over-investment in physical capital and under-investment in R&D capital for the entire sample period. By over- and under-investment, the reference is to the actual level of investment with respect to the corresponding optimal level in a perfectly competitive market. The Nadiri and Nandi study finds the values of the cost elasticities with respect to physical capital to be -0.1354. This reflects, in their view, a relatively low negative value for physical capital which may imply "excessive capital" or over-investment. The point being that investment in capital yields a modest cost saving effect of only 1.3%, an effect hardly supportive of the intensity of capital investments in this type of industry. As for R&D investment, Nadiri and Nandi find the R&D elasticity value of -0.14% indicative of the possibility of under-investment. They imply that the very fact that the overall cost saving effect of R&D investment is so minute is likely to be a reflection of its insignificant (sub-optimal) absolute level.

Table 5.5

Cost Elasticity w/r Physical Capital		Cost Elasticity w/r R&D Capital	
1960-1964	-1.098	1960-1964	0.1198
1965-1969	-1.214	1965-1969	0.1446
1970-1974	-1.146	1970-1974	0.1776
1975-1979	-1.129	1975-1979	0.1372
1980-1984	-0.808	1980-1984	0.0311
1985-1989	-1.470	1985-1989	-0.1112
1990-1994	-1.680	1990-1994	-0.32940
1995-1999	-1.894	1995-1999	-0.29070

In this model, the average cost elasticity of –1.21 with respect to physical capital for the entire sample (Table 5.5), indicates higher cost savings than the Nadiri and Nandi study, but is closer to Bernstein's 1989 results. Looking at the pre-divestiture era in particular, in which the possibility of over-capitalization was especially an issue, capital investment has had a consistent negative effect on variable cost of approximately –1.15. This in itself seems to contradict the suggestion of over-capitalization during that era. This is also consistent with Zhou's results.

Referring to the patterns of investment in R&D in the second table (Table 5.5) above, the average cost elasticity with respect to R&D capital is 0.12206 up to the year 1985. These elasticities are followed by negative elasticities in the last three sub-periods of the sample. These patterns are consistent with the view that when the focus of the firm is on new inventions or innovations of final products, the rewards of such efforts may be obscured or at best delayed until the new product (or service) is fully assimilated into the consumer market. The first decades of my sample reflect the introduction (or widespread use) of new services, such as caller ID, call waiting, 3-

way calling, and voice mail. Therefore, the positive elasticities are consistent with research and development that is "product-oriented". On the other hand, when the focus of the R&D investment is on the improvement of the *techniques* of production, the fruits of such efforts are more readily observed and quickly attained. The last decade seemed to have focused on new processes of providing telecommunications, such as Asynchronous Transfer Mode (ATM), digital subscriber line (DSL), and voice over IP (Internet Protocol). Therefore, the negative values of these elasticities (i.e., cost savings) are consistent with research and development that is "process-oriented".

It is interesting to note that R&D has been used in some studies as a proxy for technology. Christensen et al (1983), for example, have used the Bell system's R&D expenditures as a proxy for technology itself. Taking that perspective, one can take a second look at Table 5.5 from the perspective of R&D expenditures being the measures of technology. Taking that approach, it is concluded that "technology" has generally been cost increasing, with the exception of the last fifteen years of our sample. This result is consistent with my observation above that new inventions are product oriented, the monetary savings may be delayed until the new product is fully assimilated into the consumer market.

It is also interesting to note, as argued by Sahal, that with the passage of time there seems to be an increased "necessity" to increase expenditures on R&D. This, he attributes, to the increased cost of innovation in general over time, and to the fact that "easier" problems tend to be tackled first, followed by more difficult ones. This trend of increased R&D expenditures is observed, in my model, up to the pre-divestiture era. Referring to Table 5.5, there is an increase in the elasticity of cost with respect to R&D expenditures for virtually the entire pre-divestiture sub-periods. But while the evolution of a component of a system (such as a telephone loop or a router) may proceed in the direction of more complexity, the evolution of the entire system proceeds in the direction of more simplicity. This may account for the "belated" negative elasticity values in the last decade.

As for investment decisions by the firms in this industry, one can only ascertain the determinants of firm investment by tracing the effects of physical capital and R&D investments on variable cost and total revenues. I have already shown that investments in physical capital leads to a reduction in variable costs of approximately 20% per year. Investments in physical capital also lead to an annual increase in total local service revenues of 4.5% ($b_{k1}(1+1/a_1)^{-1}$). The effect of physical capital on toll service revenues is 4.43% ($b_{k2}(1+1/d_1)^{-1}$). Therefore, investments in physical capital lead to improvements in product quality which lead to an increase in service price, unless cost savings have a stronger diminishing effect (or, as in this case, the product price mark-up is considerable). An increase in service price then leads to an increase in total revenues if the product has an inelastic demand (as in local service) or to a decrease (or, as in this case, a smaller increase) in revenues if the product has an elastic demand (as in toll service).

Similarly, investments in telecommunication R&D have lead to improvements in product quality which have lead to increases in output prices. The upward pressure on output prices in the case of local service could not be curtailed due, in part, to the absence of a cost saving effect to this type of investment (i.e., the cost elasticity with respect to R&D investment). As stated above, in the case of R&D investment, the cost effect is positive (equal to 0.122 for most of the sample points). Moreover, this cost effect is stronger than the cost-saving effect of R&D investment on local revenues ($br_1 (1+1/a_1)^{-1} = -.0268$). Thus, the effect of R&D investment on total local service revenues is diminishing. The opposite effect is true of toll service. Investments in telecommunication R&D have lead to improvements in service quality which have lead to increases in service price. And though the upward pressure on service prices could not be curtailed due also, in part, to the absence of a cost saving effect, the overall effect of R&D investment in toll output on toll revenues is positive ($br_2 (1+1/d_1)^{-1} = 0.0546$).

The cost elasticity with respect to physical capital :

$$B_k + b_{kk}\,LK + b_{rk}\,.5\,LRD + g_c\,REG + b_{Lk}\,LW + b_{k1}\,LY1 + b_{k2}\,LY2 + Z_1\,LMod + Z_2\,LFib$$

The cost elasticity with respect to R&D capital:

$$B_r + b_{rr}\,LRD + b_{rk}\,.5\,LK + g_c\,REG + b_{Lr}\,LW + b_{r1}\,LY1 + b_{r2}\,LY2 + Z_1\,LMod + Z_2\,LFib$$

The cost elasticity with respect to the wage rate is:

$$b_L + b_{LL}\,dLW + g_{1w}\,REG + Z_{1w}\,LMod + Z_{2w}\,LFib + b_{L1}\,LY1 + b_{L2}\,LW + b_{Lr}\,LRD + b_{Lk}\,LK$$

The average cost elasticity with respect to the wage rate for the entire sample is approximately equal to 0.26. Hence, the wage rate is cost-increasing when it comes to the production of local and toll outputs.

Competition

Measuring the effects of competition can be carried out, as in Nadiri and Nandi (1997), by examining the discrepancy (or markup), if any, between incremental cost and actual output prices. Incremental cost is measured as variable cost per unit of output. The price markup is the difference between output price and incremental cost. In a perfectly competitive setting, the difference is zero. In other words, the larger the markup, the less competitive the market becomes.

Contrary to the intended goals of the Federal Telecommunications Act of 1996, monthly local exchange bills have not gone down. In fact, the average monthly local residential bill has not changed much since 1990. The average bill was $19.24 in 1990, compared to $19.87 in October 1999[43]. Similarly, business customer bills have not changed much since 1990. The average bill for a single line business customer was $41.21 in 1990, compared to $41.00 in October 1999. Granted that most states have imposed a moratorium or a price freeze on the rates of basic local exchange

[43] Federal Communication Commission, FCC Releases Study on Telephone Trends, Washington, D. C., December 21, 2000, Second Page of Introduction.

service, rates for optional service rates such as caller ID, call waiting, and call forwarding were exempt and hence, have not decreased in the face of new competition. It has become apparent to many local exchange (and toll) carriers that basic local services are quite lucrative. A package of a few optional services can add around $20.00 to an average customer's monthly bill. Local exchange companies, particularly the Bell companies and GTE, still command a major percentage of the local exchange market (and to a lesser extent the intrastate toll markets). In 1998, the Bell companies, along with GTE, controlled approximately 85% of the nation's 160 million local phone lines[44] .

Looking at Table 5.6 below, there is a considerable diversion between price and incremental cost for both outputs. The price markup for local service ranges between 0.90 and 2.55, while the range for toll service is between 0.83 and 8.11. These markups in and of themselves raise suspicion as to the presence of competition in this industry. It is interesting to note, however, that there is a decrease in the mark-up prices of both services starting in the 1990's. This may be a reflection of deregulation in both markets, the introduction of new technologies, and the emergence of new competitors in the market.

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[44] U. S. News & World Report May 25, 1998, p. 44.

Table 5.6

Local Service Price Mark-Up		Toll Service Price Mark-Up	
1960-1964	2.55	1960-1964	6.88
1965-1969	2.20	1965-1969	9.07
1970-1974	2.03	1970-1974	9.22
1975-1979	1.89	1975-1979	9.72
1980-1984	1.56	1980-1984	8.11
1985-1989	1.03	1985-1989	1.79
1990-1994	0.90	1990-1994	1.43
1995-1999	0.98	1995-1999	0.83
Average	1.64	Average	5.88

The mere presence of price markups does not necessarily imply sub-optimal pricing behavior. Incremental (or marginal) costs may decrease due to economies of scale or to technological advancements. Therefore, one could alternatively look at the productivity gains of competition reflected in lower costs. As stated earlier, the effects of technical progress are manifested either in increased output or in reduced costs. It has already been established that the effects of technical progress, measured by the deployment of modern switches and fiber optics, has had a negative effect on variable cost. This implies increased productivity, as incremental changes in technology have lead to higher incremental reductions in cost.

An alternative indicator of competition is the extent of technological deployment in the industry. I refer back to the results of my previous discussion on the effects of technology. I infer further from that discussion that there is some evidence of competition in the telecommunications industry, based solely on the presence of cost-saving technological deployment. The incentive to adopt new technologies is more likely to occur in a competitive environment. Newer technologies give companies a comparative cost advantage. Considering the small magnitude of the technological effect in this model, however, it is heavily discounted as a strong indicator of competition.

An alternative measure of competition is the industry's returns to scale. As stated above, the data shows decreasing returns to scale through the AT&T divestiture period. This in itself could indicate the absence of monopoly. Then results show evidence of economies of scale since 1985. However, one must exercise caution in the interpretation of returns to scale (and economies of scale). As pointed out by Evans and Heckman (1977), and others, the fact that a cost function for some aggregate measure of output exhibits scale economies is *consistent* with the absence of natural monopoly over some and possibly all of the products that comprise that aggregate. They attribute the possibility to varying product-specific economies of scale, varying output shares of total revenues, and varying demands. In the case of my model, even though I have delineated the demand and revenue aspects of local and toll outputs, I have not designated separate cost functions to each output. And while it is possible to compute output-specific economies of scale, such a measure requires output-specific cost information. No such information was available in full detail nor for the entire sample. Considering the overall empirical evidence presented so far for this model, overall economies of scale exist in the last fifteen years of the sample.

To summarize my conclusions with respect to the existence of economies of scale in the telecommunications industry since 1960, I offer the following points. The results for the pre-divestiture era, which are consistent with some previous studies, indicate that the telecommunications industry as a whole did not exhibit sure signs of natural monopolies. Lower economies of scale values in general further indicate a lack of monopoly power. In addition, higher values of economies of scale in the post-divestiture era, compared to the pre-divestiture era, are partly attributed to the emergence of other large competitors in toll market (such as MCI, Sprint, WorldCom). This in itself may also diffuse the possibility that the production of toll output may itself be exhibiting diseconomies of scale. Furthermore, tests of technical scale bias revealed evidence of excess capacity in the industry. Finally, the increasing trend in the economies of scale in the last fifteen years is attributed to an unprecedented increase in the growth rate of R&D expenditures, a high cost elasticity with respect to capital, due in part to considerable deployment of fiber optic technology, and a wave of mergers and acquisitions.

The Long Run Model

The solution to the determination of the demand for the quasi-fixed inputs constitutes the long run equilibrium condition. It is obtained by substituting the variable cost function and the capital accumulation equations into the expected value of the costs of production. Demand functions for the quasi-fixed inputs are derived using the Envelope Theorem. The theorem postulates that quantities of fixed (or quasi-fixed) inputs are at their long run equilibrium level when their shadow prices are equal to their rental prices (or the opportunity cost of their acquisition funds). The resulting demand equations then comprise the long run equilibrium conditions.

Since it is reasonable to expect[45] that in the short run, the shadow price of capital will not always equal the market price of capital due to fluctuations and discrepancies in the market, one could define the long run equilibrium level of capital as the level of capital at which the shadow price equals the market price. An implication of this is that one can distinguish short run elasticities (when the two values are not equal) from those in the long run (when the two are equal). The shadow price is the marginal reduction in cost due to a change in the quantity of a quasi-fixed factor. For example, the shadow price of capital is $\partial VC / \partial K$, which represents the one-period reduction in variable cost as the quantity of capital is increased by one unit, holding output quantity and variable input prices constant.

[45] Berndt, E., 1991, p. 484.

The cost function is as follows:

$$
\begin{aligned}
LCost =\ & b_o + b_L\ LW + g_1\ REG + g_2\ DIV + Z_1\ LMod + Z_2\ LFib + b_1\ LY1 + b_2\ LY2 + \\
& b_k\ LK + b_r\ LRD + b_{LL}\ .5(W2) + b_{11}\ .5(LY1\ LY1) + \\
& b_{22}\ .5\ (LY2*LY2) + b_{12}\ .5(LY1\ LY2) + b_{kk}\ .5(LK\ LK) + \\
& b_{rr}*.5*(LRD*LRD) + b_{rk}\ .5(LK\ LRD) + .5(Z_1\ LMod + \\
& Z_2\ LFib)^2 + g_{1k}(REG\ LK) + g_{1r}(REG\ LRD) + \\
& g_{1w}\ (LW*REG) + Z1w*(dLW\ dMod) + Z2w\ (dLW\ dLFib) + \\
& g_{1a}\ (LY1\ REG) + g_{2a}\ (REG\ LY2) + b_{L1}(LW\ LY1) + b_{L2} \\
& (LW\ LY2) + b_{Lr}\ (LW\ LRD) + b_{Lk}\ (LW\ LK) + b_{k1}\ (LY1\ LK) + \\
& b_{k2}\ (LY2\ LK) + b_{r1}\ (LY1*LRD) + b_{r2}\ (LY2*LRD) + Z_1(LY1 \\
& LMod) + Z_2\ (LY2\ LFib) + Z_1(LY1\ LMod) + Z_2\ (LY1\ LFib) + \\
& Z_1(LK\ LMod) + Z_2\ (LK\ LFib) + Z_1(LRD\ LMod) + \\
& Z_2\ (LRD\ LFib) \qquad (2.1)
\end{aligned}
$$

All variables are as previously defined; however three modifications are added to the model. First, the coefficients of the growth rates of the technology variables (Z_{11} and Z_{22} in equation 1.1) are assumed to be the same as those of the slope variables (Z_1 and Z_2). Second, the effects of regulation on the use of capital and R&D are assumed not to be the same (g_{1k} is assigned for capital and g_{1r} for R&D). Third, the effects of regulation on local and toll outputs are assumed not to be the same (g_{1a} is assigned for local output and g_{2a} for toll output). The rationale behind the first assumption is to smooth the sporadic patterns of growth rates of the logs of modern switches and fiber optics. The rationale behind the second and third assumptions is that regulation tends to have delayed and distinct effects. Considering that in the long run, it is assumed that the industry has had the opportunity to fully adjust to all the effects of regulation, it is therefore logical to model these effects separately.

Demand functions for the quasi-fixed inputs are derived using the Envelope Theorem. Fixed factors are at their long run equilibrium level when their shadow prices are equal to their rental prices. As stated previously, the shadow price is the marginal reduction in cost due to a change in quantity of a quasi-fixed factor. The physical capital share equation is:

$$S\,k = b_K + b_{kk}\,LK + b_{Lk}\,LW + b_{rk}\,LRD + b_{k1}\,LY1 + b_{k2}\,LY2 + g_c\,REG + Z_1\,LMod + Z_2\,LFib + bkk\;Klag \tag{2.2}$$

The R&D capital share equation is:

$$S\,RD = b_r + b_{rr}\,LRD + b_{rk}\,LK + b_{Lr}\,LW + b_{r1}\,LY1 + b_{r2}\,LY2 + g_c\,REG + Z_1\,LMod + Z_2\,LFib + brr\;RDlag \tag{2.3}$$

The long run equations are derived as follows (using capital share as an example):

$$S\,k = (r\,.\;K) \,/\, VC$$

The rate of interest (i.e., price of capital) is equal to the derivative of cost with respect to capital, or $r = \partial\, VC \,/\, \partial\, K$. Therefore, $S\,k = (\partial\, VC \,/\, \partial\, K)\,(K \,/\, VC) = \partial \ln VC \,/\, \partial \ln K$. The long run model consists of the cost equation (2.1), the physical capital share equation (2.2), the R&D capital share equation (2.3), the labor share equation (1.4) and the output demand equations (1.2 and 1.3).

Estimation Results

At first glance, the model overall fits the data well, as indicated by the mostly low standard error values (Table 6) and by the mostly high R^2 values[46] (reported in Table 7) However, further tests and observation will reveal that this model may not depict the data as well as the short run model.

The overall significance of every equation was tested using a Wald Chi-Square test. The results are listed below in Table 7. All equations are significant at least at the 95% level, with the exception of the R&D capital share equation. This is in comparison to the short-run model for which all equations are statistically significant.

Wald tests were also performed to test for the significance of the explanatory variables. Results are compiled in Table 8 below. The local output variables and the technology variables are statistically insignificant. There are also high P-values for some of the variables.

[46] An exception is the R&D capital share equation.

Table 6

COEFFICIENT	COEFFICIENT VALUE	ST. ERROR
BL	0.37435	0.48195
B1	1.3762	0.67133
B2	-0.022659	0.31792
BK	-0.50933	0.25706
BR	0.074793	0.12807
BLL	0.21082	0.11482
B11	-0.32435	0.090729
B22	0.0036251	0.0074245
B12	0.0024229	0.0070137
BKK	0.0015719	0.0006623
BRR	0.0004509	0.0002045
BRK	-0.042881	0.016264
G1	-0.00068456	0.0009578
Z1	-0.0013474	0.0022274
Z2	0.0010355	0.0009133
GC	-0.0034973	0.002046
G1K	-1.4931	4.6192
G1R	-0.33905	0.57123
G1W	-1.0252	1.4164
G1A	0.52361	2.9000
G2A	0.59960	1.8470
BL1	-0.012177	0.087009
BL2	-0.0096468	0.011000
BLR	-0.0082340	0.015112
BLK	0.043469	0.099685
BK1	0.11762	0.023055
BK2	-0.0084603	0.010043
BR1	0.039857	0.014018
BR2	-0.0009848	0.0024893
Demand Equations		
A1	-0.28242	0.079296
A2	0.43653	0.39605
A3	1.3036	0.24764
D1	-0.92012	0.06217
D2	0.85157	0.090801
D3	0.012189	0.092025
D4	0.039809	0.017237
D5	0.69066	0.16179

Table 7

Tests of Overall Equation Significance

Local Demand Equation WALD CHI-SQUARE STATISTIC = 13440.261 WITH 3 D.F. P-VALUE= 0.00000 R-SQUARE BETWEEN OBSERVED AND PREDICTED = 0.9998
Toll Demand Equation WALD CHI-SQUARE STATISTIC = 124122.36 WITH 5 D.F. P-VALUE= 0.00000 R-SQUARE BETWEEN OBSERVED AND PREDICTED = 0.9997
Cost Equation WALD CHI-SQUARE STATISTIC = 5704.6822 WITH 27 D.F. P-VALUE= 0.00000 R-SQUARE BETWEEN OBSERVED AND PREDICTED = 0.9974
Local Revenue Equation WALD CHI-SQUARE STATISTIC = 2105.0224 WITH 9 D.F. P-VALUE= 0.00000 R-SQUARE BETWEEN OBSERVED AND PREDICTED = 0.9127
Toll Revenue Equation WALD CHI-SQUARE STATISTIC = 51449.298 WITH 9 D.F. P-VALUE= 0.00000 R-SQUARE BETWEEN OBSERVED AND PREDICTED = 0.8621
Labor Share Equation WALD CHI-SQUARE STATISTIC = 252.41012 WITH 8 D.F. P-VALUE= 0.00000 R-SQUARE BETWEEN OBSERVED AND PREDICTED = 0.8756
Physical Capital Share Equation WALD CHI-SQUARE STATISTIC = 269.14510 WITH 8 D.F. P-VALUE= 0.00000 R-SQUARE BETWEEN OBSERVED AND PREDICTED = 0.8537
R&D Capital Share Equation WALD CHI-SQUARE STATISTIC = 12.179347 WITH 8 D.F. P-VALUE= 0.14338 R-SQUARE BETWEEN OBSERVED AND PREDICTED = 0.0200

Table 8

Tests of Overall Variable Significance

```
Labor Variables

WALD CHI-SQUARE STATISTIC =  262.11214   WITH   7 D.F.  P-VALUE= 0.00000
UPPER BOUND ON P-VALUE BY CHEBYCHEV INEQUALITY = 0.02671
```

```
Capital Variables

WALD CHI-SQUARE STATISTIC =  40.966964   WITH   6 D.F.  P-VALUE= 0.00000
UPPER BOUND ON P-VALUE BY CHEBYCHEV INEQUALITY = 0.14646
```

```
RD Variables

WALD CHI-SQUARE STATISTIC =  11.224955   WITH   5 D.F.  P-VALUE= 0.04710
UPPER BOUND ON P-VALUE BY CHEBYCHEV INEQUALITY = 0.44544
```

```
Technology Variables

WALD CHI-SQUARE STATISTIC =  1.4487235   WITH   2 D.F.  P-VALUE= 0.48463
UPPER BOUND ON P-VALUE BY CHEBYCHEV INEQUALITY = 1.00000
```

```
Local Output Variables

WALD CHI-SQUARE STATISTIC =  124.16367   WITH   9 D.F.  P-VALUE= 0.00000
UPPER BOUND ON P-VALUE BY CHEBYCHEV INEQUALITY = 0.07248
```

```
Toll Output Variables

WALD CHI-SQUARE STATISTIC =  2.0342250   WITH   9 D.F.  P-VALUE= 0.99091
UPPER BOUND ON P-VALUE BY CHEBYCHEV INEQUALITY = 1.00000
```

```
Regulation Variables

WALD CHI-SQUARE STATISTIC =  9.1562915  WITH   6 D.F.  P-VALUE= 0.16498
UPPER BOUND ON P-VALUE BY CHEBYCHEV INEQUALITY = 0.65529
```

Looking at the performance of the various elasticities, there are mixed results. Some elasticities have behaved as expected, in the sense of becoming larger in (absolute) value, while others have became smaller or have changed signs. Looking at the scale elasticity, it has increased in the 1969-1985 period from 0.88 in the short run to 1.07 (Table 9.1). This is to be expected as the passage of time and the concurrent opportunity for full adjustment to market fluctuations is likely to show some delayed effects of cost savings. This in turn is reflected in higher economies of scale. The same applies to the last sub-periods, in which the measure of scale elasticity rises from 1.20 in the short run to 1.67.

Table 9.1

Scale Elasticity

1960-64	1.07
1965-69	1.07
1970-74	1.07
1975-79	1.07
1980-84	1.06
1985-89	1.06
1990-94	1.67
1995-99	1.67
Average	1.217

Looking at the cost elasticity with respect to local output, its value had decreased, contrary to what is expected (Table 9.2). The performance of the cost elasticity with respect to toll service is more peculiar, as it changes sign for most of the sample sub-periods.

Table 9.2

Cost Elasticity with Respect to Local Output Output

Table 9.3

Cost Elasticity with Respect to Toll

1960-64	1.35	1960-64	-.023
1965-69	1.35	1965-69	-.024
1970-74	1.35	1970-74	-.023
1975-79	1.36	1975-79	-.023
1980-84	1.36	1980-84	-.021
1985-89	1.36	1985-89	-.022
1990-94	1.36	1990-94	0.57
1995-99	1.36	1995-99	0.57

Technical Change

As reported in Table 9.4 (a), the long run model yields positive values for the elasticity of cost with respect to modern switch technology. The elasticity with respect to fiber is negative throughout the sample period. It is possible that, in the long run, the cost-saving effects of technology diminish or even cease to exist. However, considering the overall effects of the technology variables (failing the statistical significance test), the results are questionable.

Table 9.4 (a)

Modern Switches

Table 9.4 (b)

Fiber

Average (1960-1999)	0.0015	Average (1960-1999)	-0.0013

Investment Patterns:

There is a decrease in the cost elasticities with respect to both types of capital for the sub-periods before 1990. This is contrary to economic theory and actual observations. Therefore, these results are questionable. In the post 1990 period, the cost elasticity with physical capital does increase, whereas the cost elasticity with respect to R&D capital does not. Again, these results are dismissed in favor of the short run version.

Table 9.5

Cost Elasticity with Respect to Capital

Table 9.6

Cost Elasticity with Respect to R&D Capital

Average 1960-1989	-0.50	Average 1960-1989	0.073
Average 1989-1999	-1.99	Average 1960-1999	-0.26

The cost elasticity with respect to regulation increased in the long run, as expected. The effects of a regulatory stimulus on cost are expected to manifest more clearly in the long run, as adjustments in the industry have been accounted for in response to that stimulus. The increase, however, is not significant. The average elasticity increased from .09 in the short tun to 0.10.

Table 9.7

Cost Elasticity With Respect to Regulation

1960-64	-.141
1965-69	-.095
1970-74	-.134
1975-79	-.081
1980-84	-.145
1985-89	-.076
1990-94	-.068
1995-99	-.086
Average	-0.1032

Output Demand Elasticities in the Long Run

Estimation results show (Table 7) that the long run demand elasticities are higher in value than the short run, except for the price elasticity of local service and the elasticity of local output with respect to the number of lines. While the later may be justifiable on the grounds that percentage increases in the number of lines will eventually lead to lesser percentage increases in the total number of calls per year. The same argument cannot be put forth, however, for the price elasticity of local output. Empirical evidence overwhelmingly supports the observation that price elasticities of most goods and services increase with the passage of time.

Therefore, based upon the overall performance of the various elasticities and the mixed results of the tests of significance, I am inclined to discount the long run model as a good fit for the data.

ALTERNATIVE MODELS

THE NADIRI AND NANDI MODEL

I attempted to replicate the results of the Nadiri and Nandi (1997) model using the actual data set (1950-1987). To correct for serial correlation, I first applied the conventional method of transforming the data using the Cochrane-Orcutt approach. Then I applied the Prais-Winsten approach. The model failed to converge (i.e., reach a solution) under both approaches in spite of repeated attempts. I attribute these failures to one or more of the following reasons: (1) the exact method of correction for serial correlation in the Nadiri and Nandi study was not made available, (2) the choice of instrumental variables was not made available, and (3) the choice of software packages is different[1].

Next, I attempted to estimate the Nadiri and Nandi model using my own data set for 1960-1999[2]. I resorted to the method of first differences, as a means for correcting for serial correlation. As a result, the time variable was eliminated, but the model converged and reached a global solution. Reported below (Table 1) are the

---

[1] The software package used in the Nadiri and Nandi (N&N) study is SAS. The software package used in this research is SHAZAM. According to J. Silk (1996), SAS offers more flexibility with options than SHAZAM (in linear estimation). If, by extension, this lack of flexibility applies to non-linear estimation, it may account for the failure of replicating the results of the N&N model.

[2] I attempted to replicate the results of the N&N short-run model using the method of first differences, but the model failed to reach reasonable solutions.

short-run model results. Overall, the model fits the data well, as indicated by the mostly low standard error values and the high R^2 values (Table 2).

Table 1 The Short Run Model

COEFFICIENT	Value	ST. ERROR
B1	1.7390	1.7128
B2	-0.27030E-01	0.28236
BL	0.29330	0.39780
BK	-0.73817	1.0090
BR	-0.37436E-01	0.28902
B11	0.91745	0.62005
B22	-0.24623E-02	0.18222E-01
B12	0.32937E-01	0.32961E-01
BLL	0.19412	0.10965
BKK	1.1127	3.0928
BRR	0.28510	1.0419
BRK	2.2919	7.8610
G1	0.10158E-03	0.22364E-02
G2	-0.11103E-01	0.33916E-01
GC	-0.98291E-01	0.36388
G1W	-1.1494	0.51897
GYA	0.16922	0.49555
BL1	-0.39021E-01	0.89653E-01
BL2	-0.17225E-01	0.25689E-01
BLR	-0.11097E-01	0.31578E-01
BLK	0.85592E-01	0.10440
BK1	-1.5312	0.94946
BK2	-0.45195E-01	0.44850E-01
BR1	0.26043	0.18875
BR2	-0.23632E-02	0.80376E-02
A1	-0.20741	0.08962
A2	0.38602	0.28520
A3	1.3210	0.18034
D1	-0.81156	0.11596
D2	0.75146	0.14191
D3	0.89799	0.24887
D4	0.17776	0.23313

Performance of Elasticities:

Results of estimated elasticities are compiled and reported below in Table 2. Considering the divergence in the size and scope of my sample and N&N's (1997), direct comparisons cannot be made between the two models. Comparisons can be drawn, however, between the model above (i.e., using the N&N set-up) and my applied model. The estimated elasticities for the most part are different. I attribute the differences to my use of technology variables, which enter the definitions of these elasticities. For instance, the cost elasticities with respect to physical capital are different (-0.67477 compared to –1.21 in our model). The reason for the divergence in values is partly due to the role of technology in the production process. The deployment of advanced technology leads to a more significant (i.e., more elastic) effect on cost (more cost-savings). On the other hand, the elasticities with respect to R&D capital are dissimilar. My results show a positive elasticity of approximately 0.10 through 1989, while the model above shows a negative elasticity of approximately –0.030 for the same period. I attribute the role of technology in R&D investment in this case to be cost-using, whereas in the above-model, technology is not accounted for directly. The cost elasticities of R&D change signs in the 1990s under both models.

Overall, the estimated demand elasticities of my model are consistent with the model above. One exception is the price elasticity of local exchange service. Its value is -0.20 in the above model compared to –0.45 in my model. I attribute the difference to the indirect role of wireless telecommunications services as an increasingly important substitute for traditional telephone service.

Table 2 The Short Run Model

Cost Elasticities

LOCAL OUTPUT COST ELASTICITY		TOLL OUTPUT COST ELASTICITY	
1960-1964	1.772	1960-1964	-0.03125298
1965-1969	1.792	1965-1969	-0.03124739
1970-1974	1.786	1970-1974	-0.03109262
1975-1979	1.780	1975-1979	-0.03166015
1980-1984	1.784	1980-1984	-0.03002030
1985-1989	1.754	1985-1989	-0.02963525
1990-1994	1.934	1990-1994	0.14030540
1995-1999	1.936	1995-1999	0.14018160
Average	1.817	Average	0.097

CAPITAL COST ELASTICITY		R & D COST ELASTICITY	
1960-1964	-0.5552	1960-1964	0.10072
1965-1969	-0.6358	1965-1969	0.10424
1970-1974	-0.5758	1970-1974	0.13002
1975-1979	-0.5718	1975-1979	0.11060
1980-1984	-0.4528	1980-1984	0.10134
1985-1989	-0.7926	1985-1989	0.05511
1990-1994	-0.8554	1990-1994	-0.09201
1995-1999	-0.9588	1995-1999	-0.10628
Average	-0.67477	Average	0.3024

Scale Elasticity	
1960-1964	0.8324
1965-1969	0.8664
1970-1974	0.8214
1975-1979	0.8324
1980-1984	0.7674
1985-1989	1.0286
1990-1994	0.9340
1995-1999	0.9939
Average	0.8845

Table 3

Tests of Equation Significance

Local Demand Equation				
WALD CHI-SQUARE STATISTIC =	24684.035	WITH	3 D.F.	P-VALUE= 0.00000
Toll Demand Equation				
WALD CHI-SQUARE STATISTIC =	60661.773	WITH	4 D.F.	P-VALUE= 0.00000
Cost Equation				
WALD CHI-SQUARE STATISTIC =	16387.067	WITH	25 D.F.	P-VALUE= 0.00000
Local Revenues Equation				
WALD CHI-SQUARE STATISTIC =	4221.9880	WITH	7 D.F.	P-VALUE= 0.00000
Toll Revenues Equation				
WALD CHI-SQUARE STATISTIC =	7.8482575	WITH	7 D.F.	P-VALUE= 0.34616
Share of Labor Equation				
WALD CHI-SQUARE STATISTIC =	58.903112	WITH	6 D.F.	P-VALUE= 0.00000

Table 4

Additional Tests

Cost Equation		
DURBIN-WATSON = 2.2485	VON NEUMANN RATIO = 2.3047	RHO = -0.17547
R-SQUARE BETWEEN OBSERVED AND PREDICTED = 0.9975		
Local Output Demand Equation		
DURBIN-WATSON = 0.7408	VON NEUMANN RATIO = 0.7593	RHO = 0.63128
R-SQUARE BETWEEN OBSERVED AND PREDICTED = 0.9998		
Toll Output Demand Equation		
DURBIN-WATSON = 1.2139	VON NEUMANN RATIO = 1.2442	RHO = 0.38836
R-SQUARE BETWEEN OBSERVED AND PREDICTED = 0.9996		
Local Revenue Equation		
DURBIN-WATSON = 1.4206	VON NEUMANN RATIO = 1.4561	RHO = 0.28538
R-SQUARE BETWEEN OBSERVED AND PREDICTED = 0.9571		
Toll Revenue Equation		
DURBIN-WATSON = 2.5318	VON NEUMANN RATIO = 2.5951	RHO = -0.28143
R-SQUARE BETWEEN OBSERVED AND PREDICTED = 0.8600		
Labor Share Equation		
DURBIN-WATSON = 1.7677	VON NEUMANN RATIO = 1.8119	RHO = 0.11528
R-SQUARE BETWEEN OBSERVED AND PREDICTED = 0.8761		

ALTERNATIVE MODEL SPECIFICATIONS

At the start of this research, a smaller sample size was considered. However, as more variables were added, with corresponding interactive variables, the number of sample observations became close to (sometimes exceeding) the number of unknown parameters. This rendered the simultaneous estimation of all these parameters impossible. Therefore, the sample size was increased to forty observations allowing for two degrees of freedom in the final version of the model.

Initially, time was used as a variable in the cost function, but due to the use of the method of first differences, the time variable was eliminated. On the demand side, I experimented with various alternatives as far as the choice of explanatory variables, particularly with the wireless industry variable (as explained below). I also considered a service-sector variable (as in the Nadiri and Nandi model) in the toll output demand equation, but it did not alter the outcome of the model.

Six model specifications for the cost function were considered based upon theoretical and technical assumptions. The following statistical tests were conducted in order to determine the validity of each specification: single-equation Wald Chi-Square tests and variable significance Wald Chi-Square tests. The tests for each model produced mixed results, which were overall unsatisfactory. I explore each case separately in the following section.

Model Two - No Instrumental Variables

Model Two, which dispenses of the use of instrumental variables, produced favorable results under single-equation Wald Chi-Square tests (at the 95% level). But comparing the results to the applied model, the Wald Chi-Square values diminished in some equations. In addition, the adjusted R^2 value for the cost equation diminished. This indicates that the exclusion of the instrumental variables is not recommended, as it reduces the model's explanatory power. Furthermore, Model Two failed to produce significant Wald Chi-square values for the cost equation variables, except for fiber and wages, raising the question of model mis-specification.

Model Three- No Divestiture Variable

Model Three, which differs from my applied model in that it does not contain a divestiture dummy variable, produced favorable results under single-equation Wald Chi-Square tests. However, the model produced only three significant coefficient values. As expected, the elimination of the divestiture dummy in this case did not alter the value of R^2 of the cost function. Typically adding dummy variables may inflate R^2, so removing one could deflate it. But considering that the divestiture variable failed the t-test (St. error 0.024441 and t-value 0.52187), this is to be expected.

Model Four – Separate Effects of the Regulation Variable on Capital

Model Four, which separates the effects of the regulatory variable on both capital variables, produced favorable results of the single-equation Wald Chi-Square test. However, the model did not produce significant coefficient values for the regulatory variable itself. The physical capital and R&D capital variables were found to be significant which is not surprising, since their effects on variable cost were allocated separate coefficients. Incidentally, Model Four is the only model to produce a significant R&D cost coefficient (at the 90% level).

Model Five - The Effect of Regulation on the Wage Rate is Suppressed

Regulation, per se, may not be a significant determinant of the level of wages in the telecommunications industry. Granted the nature and stringency of regulation affects the industry's rate of factor substitution and, hence, its utilization of labor, there are a host of other determinants that affect wages as well. These determinants include taxes, the price of capital, labor productivity, worker's age and experience, and market structure. Therefore, I have considered suppressing the effect of regulation on the wage rate in Model Five. Results show favorable results for single-equation Wald Chi-Square tests. However, the model produces only three significant coefficients and that is of physical capital, fiber and wages. As such, this model specification was rejected.

Model Six – The Effect of Technology on the Wage Rate is Suppressed

Theoretically, the effects of technology on wages are two-fold and possibly contradictory. Advancements in technology promote the use of physical capital, which if the labor-capital substitution is negative, leads to a reduction in the demand for labor. This then leads to a reduction in the market wage rate, assuming all else is constant. Yet advancements in technology are only possible through the knowledge and experience of labor. Thus, an increase in the demand for labor leads to an increase in its market wage- assuming all else is constant. I considered in Model Six to suppresses the effects of technology on the wage rate. Results of single-equation Wald Chi-Square tests produced favorable results for all equations. As for the significance of variables, only the wage and physical capital variables were found to be significant. My conclusion is that the exclusion of the technology-wage interactive terms is counter-productive to the model.

Model Seven – No Regulatory Interactive Terms

Model Seven, which has no regulatory interactive terms, shows significant coefficients for all variables, except toll output, R&D capital and modern switches. Results of single-equation Wald Chi-Square tests produced favorable results for all equations. The R^2 value for the cost equation, however, dropped to 0.9942 (from 0.997 in the applied model). The t-value for the regulatory variable (now having no interactive terms) is higher than the original model's (though significant only at the 80% level) and equal to -1.546, compared to -0.8695.

Model Eight - Model Seven with Only Modern Switches for the Technology Variable

Model Eight is similar to Model Seven, except that it eliminates the fiber optic variable altogether as one of the two technology variables in the model. Results of single-equation Wald Chi-Square tests produced favorable results at the 95% for all equations. But this specification failed to produce significant values for toll output and R&D capital. It is concluded that the excluding the modern switch variable does not enhance the performance of the model. Therefore, the inclusion of at least two technology variables improves model performance. Not only does it enhance the model statistically, but it provides for a broader and more realistic representation of the actual state-of-the-art technology.

Variations in the Toll Output Demand Equation

Several variables capturing the effects of wireless telecommunications on the demand for traditional (i.e., land-wire) toll services were also considered. These variables include the nation-wide number of wireless subscribers, the number of cell cites, the average length of wireless calls, the annual revenues of the wireless industry in the U. S., the industry level of investment and the average customer monthly bill.

Results are reported below in Table 5. The most striking result is the higher-than-typical value for the price elasticity of local output demand, A1 (in the neighborhood of -0.75). The remaining elasticities are fairly stable. The closest overall results to the applied model were obtained with the last variable specification- the average wireless monthly bill. It produced a reasonable price elasticity of local output demand of -0.30846. The cross price elasticity between wireless services and toll output demand (D4) is unfortunately very small (in the neighborhood of -.0025). It is largest in the case of average length of wireless calls (which incidentally is the second best overall performance of these demand specifications).

Table 5

Output Demand Elasticities of the Short Run Model with Alternative Variables for the Wireless Industry [3]

Number of Cell Cites Nation-wide			Annual Investment in the U. S. Wireless Industry		
A1	-0.74195	0.74634E-01	A1	-0.78255	0.72680E-01
A2	0.57195	0.39645	A2	0.62415	0.43282
A3	1.3104	0.24721	A3	1.2861	0.26974
D1	-0.78978	0.59159E-01	D1	-0.80190	0.61012E-01
D2	0.73440	0.11012	D2	0.72897	0.11138
D3	0.86379	0.19699	D3	0.87777	0.19883
D4	**-0.55005E-02**	0.35430E-02	**D4**	**-0.23217E-02**	0.17952E-02

[3] A1, A2 and A3 are the local output demand coefficients with respect to own price, real GDP, and number of lines, respectively. D1, D2, D3, and D4 are toll output demand coefficients with respect to own price, real GDP, number of lines and the applicable wireless variable, respectively.

Table 5 Continued

Number of Wireless Subscribers in the U.S.			Average Wireless Monthly Bill		
A1	-0.77617	0.72634E-01	A1	-0.30846	0.10200
A2	0.62504	0.42579	A2	0.39028	0.32122
A3	1.2842	0.26536	A3	1.3383	0.20320
D1	-0.79530	0.61203E-01	D1	-0.83418	0.64175E-01
D2	0.73251	0.11215	D2	0.73578	0.10868
D3	0.86908	0.20015	D3	0.87531	0.19325
D4	**-0.26970E-02**	0.19381E-02	**D4**	**-0.85171E-02**	0.51310E-02

Average Length of Wireless Calls			Total Revenues in the U. S. Wireless Industry		
A1	-0.58307	0.84660E-01	A1	-0.78323	0.72598E-01
A2	0.42256	0.33739	A2	0.61712	0.43972
A3	1.3721	0.21179	A3	1.2905	0.27402
D1	-0.77853	0.60374E-01	D1	-0.79480	0.61981E-01
D2	0.58680	0.10909	D2	0.72482	0.11280
D3	1.1360	0.19613	D3	0.88329	0.20119
D4	**-0.42583E-01**	0.28232E-01	**D4**	**-0.24155E-02**	0.19003E-02

CONCLUSIONS

The absence of government intervention in the telecommunications industry does not necessarily guarantee the emergence of competition. Market conditions inherent to the industry circumscribe competitive forces. As a result, certain sectors of the industry are suited for some degree of regulatory oversight.

My research confirms monopolistic tendencies in certain areas of the industry, and the emergence of competition in others. The finding of significant economies of scale over the past fifteen years suggests the potential for monopoly. These scale economies may be attributable to an overall increase in R&D investment as well as significant savings from fiber optic investments. The recent trend of corporate mergers and acquisitions may be interpreted as strategic moves to retain and strengthen market share. Monopoly power is also indicated by the finding the most efficient firm size is smaller than current market size. The implication of excess capacity is supported by recent evidence, particularly with respect to fiber optic related output.

Findings indicative of greater competition include slower price-markups for both local and toll outputs since divestiture. This finding indicates diminishing market power of telecommunications companies. In addition, my estimates of the price elasticity of toll service demand are higher than earlier studies. This greater price responsiveness may be due to the increasing use of wireless services, a new and vital substitute for traditional telecommunications services. My empirical findings further indicate that technological advancements, due to investment in physical capital and R&D, have lead to significant cost efficiencies in the production of local services. Greater technological innovations in turn are more likely in a competitive environment.

Interestingly, my research indicates that the rate at which variable costs decline over time does not depend on the scale of operation. Consequently, smaller firms may be able to diffuse technology through R&D and capital expenditures, marketing techniques, and cost efficiencies as quickly as larger firms. For example, the availability of digital telephone switches in a wide range of sizes and prices allows smaller firms to have ownership of a significant part of the network. This allows smaller firms to individually capture the many practical and economic advantages of advanced switch deployment. These cost and technological factors will promote entry of small and medium sized firms into the market and thereby increase competition.

Given this combination of monopolistic and competitive elements, what is the proper regulatory approach? One approach is alternative or relaxed regulation, or simply deregulation. A priori, deregulation has the potential to both reduce and increase firm costs. Cost reductions may flow from few rate reviews and case filings; less frequent and less extensive litigation; and lower reporting requirements. Relaxed regulation may also reduce firm investment risk by reducing uncertainty about the regulator's next move. On the other hand, deregulation may increase costs. New categories of post-deregulation costs, such as network interconnection and collocation costs, along with new performance standards concerning, among other things, quality and promptness of carrier-to-carrier services, and new compliance requirements could raise telecommunications firm costs. My empirical estimates, however, indicate that deregulation has contributed to significant cost savings, increased technology deployment, and competitive output prices.

Yet the question of more or less regulation must address not only the cost aspects of regulation, but also its theoretical foundations. Approaches to economic thought and the associated practical tools of analysis must continually adapt to the structural changes of the industry. Analysts and regulators alike must be willing to rethink economic theory when necessary. For example, the notion of pure or perfect competition as a blueprint for deregulation is impractical. The assumptions of a large number of sellers, perfect information and a homogeneous product must be relaxed or discarded altogether. Instead, focus should be placed on *effective* or workable competition which seeks to achieve the essential outcomes of pure competition without strict adherence to its restrictive conditions. The essential idea behind effective competition is that there is enough competition to prevent any one firm or a small group of firms to have market control. Moreover, there is enough competition to facilitate easy entry, better service quality and optimal economic efficiency. As such, effective competition could accommodate possibly five or six sellers of various sizes; information may not be perfectly assimilated; and there may be some variation in product characteristics. Measures of competition available to regulators must also be flexible and diverse. In addition to the standard industrial organization definitions, there are indirect measures, such as increased productivity, increased technological deployment, diminished economies of scale and scope, lower output prices, and increased efficiency. There are also new measures of competition applicable to local exchange markets. They include the number of interconnection and resale agreements, the discount rates for resellers of local exchange service, and the nature of carrier-to-carrier relations.

Policy Recommendations

My policy recommendations consist of six main points. The first recommendation is an efficient coordination by the public and private sectors of different telecommunications technologies and technology sectors. Efforts must be made to avoid unnecessary duplication of networks, to ensure compatibility of technologies, and to facilitate constructive interaction between various technology sources. This may be achieved through further facilitation of network interconnection and line sharing through modified rules and regulation; the creation of a national organization consisting of private and public members to serve as a forum for the exchange of ideas; and the prompt standardization of network elements, including new and diverse technologies.

The second recommendation is an earmarked promotion of technological deployment and diversification. Since advanced technologies may be more product-oriented than process-oriented, this may put an upward pressure on production costs rather than lowering them. Policy makers must provide special incentives for investment in *new* technologies, through cash grants, higher depreciation rates, and opportunities for higher rates of return on investment. Special deference to smaller-sized companies may be necessary, as they often posses pioneering ideas, but lack the necessary funding.

The third recommendation is to exercise caution against inefficient mergers and acquisitions. In light of the anti-competitive effects of recent mergers and acquisitions, in which the increasing size of existing companies coupled with evidence of increased economies of scale, policy makers must exercise restrain in granting approval to such corporate moves.

The fourth recommendation is the promotion of telecommunications infrastructure investment in physical capital and R&D by offering economic incentives and rewards. Considering that the major cost components of fiber optic deployment and telephone switches are considerable and irreversible, investment in networks is largely non-recoverable. The role of policy makers then is to provide investment incentives in R&D and in new technologies. Capital investment in the last forty years has consistently lowered variable cost. This in itself lends support against concerns of possible over-capitalization.

The fifth recommendation is for continued deregulation of competitive services in both the local and toll markets. Regulatory agencies must continue the goals of the Federal Telecommunications Act of 1996, whereby more competition is attained in local and toll markets.

The final recommendation is for regulators and practitioners to rethink economic theory when it comes to cost studies, production models, efficiency measurements, monopoly assessment, and output demand projections. Focus must shift to the use of technology variables in the definitions of cost, economies of scale, and output demand. Production functions must attempt to depict production relationships in a realistic manner representing techniques actually in use rather than a simple time trend or some theoretical conception of technology. Industry output demand projection study must be enhanced by the use of substitute and/or complementary services, such as wireless services, internet telephony, and e-mails.

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APPENDIX 1

DEREGULATION IN THE U. S. TELECOMMUNICATIONS INDUSTRY

Alternative regulation plans in telecommunications include many arrangements, some of which are applied in combination with others. Following are the main categories of alternative regulation:

(1) Profit Sharing – a system in which an allowed earnings range is established by the regulatory agency to be fully retained by the firm. Earnings in excess of this allowed range are split between the firm and the rate payers. Receipt of these earnings by rate payers may be realized through a consumer credit, future rate reductions, or service infrastructure improvements. If earnings fall below the established range, various options are available to the firm, including reverting back to rate-of-return regulation or another plan.

(2) Revenue Sharing- this system is similar to profit sharing, only it pertains to the total revenues of regulated services.

(3) Price Regulation – under this system, prices are regulated, not rate of return. All earnings are retained by the firm. It is less restrictive than revenue sharing and profit sharing. An example of price regulation is price cap regulation, in which maximum price levels are established and the firm retains any incremental earnings above cost. In addition, most plans include an annual target for

productivity improvement that the company must achieve before it receives financial gains. This target is usually implemented by requiring (inflation-adjusted) prices to decline by a pre-designated productivity "offset". Another form of price regulation is price freezes, which are usually applied to local exchange services for a pre-specified period of time.

(4) Partial or Piecemeal Regulation – a system in which some categories of services are deregulated, or subject to less regulation, and others remain regulated. Categories subject to less or no regulation include competitive services or optional services.

Price cap regulation was first adopted by the FCC in 1989, when it set price caps for AT&T. The productivity offset was set at 3%, which was the sum of AT&T's historical productivity growth of 2.5%, and a consumer "dividend" of 0.5%. Later in 1990, the FCC implemented price cap regulation to interstate access charges of local exchange carriers. However, their plan was different in that it included profit sharing. LECs were also given the choice of compensation plans. Soon after, many state followed suit and applied price cap regulation to local service rates. By July 1999, thirty-nine states had implemented some form of alternative regulation.

Source: Literature distributed at the National Association of Regulatory Utility Commissioners (NARUC) 1997 Summer Meeting in Lansing, MI.