Journal of Regulatory Economics; 6:381–398 (1994)

Economies of Scope in the Local Telephone Exchange Market[1]

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Abstract
Using cost data generated by an optimization model, we evaluate the degree of economies of scope in the local telephone exchange market. We find that economies of scope between switched and non-switched services are a decreasing function of customer density, while there are strong economies of scope, regardless of customer density, within the switched telephone market.

1. Introduction

Beginning with the licensing of private microwave systems in the years immediately following World War II, the Federal Communications Commission (FCC) began issuing a series of decisions which have encouraged entry into the telephone industry. At each stage in which a further reduction in legal barriers-to-entry was considered, policymakers were confronted with the welfare effect of moving from a monopoly to oligopolistic or competitive market structure. Economists have contributed to this discussion by analyzing the cost structure of the industry.

The contribution made by economists has been constrained by the quality of the data. Economists have primarily used Bell System data to examine the extent to which the industry is a natural monopoly. No observations were available on the cost of having two or more

1 The authors gratefully acknowledge partial funding from the National Regulatory Research Institute at the Ohio State University. This work was made possible in part by research computing facilities provided by the City University of New York and Tulane University. We thank Editor Michael Crew, two anonymous referees, and David Malueg for useful comments and suggestions. Remaining errors are, of course, our own responsibility.

The computer software (compiled for use on MS-DOS machines) and user instructions developed for this paper are available at reproduction cost from the authors at either address. The authors are willing to collaborate with interested researchers in modifications of the source code; however, source code will not be distributed due to confidentiality restrictions.

firms serve the same market. Lacking observations for firms which provided only part of th industry vector of outputs, tests for subadditivity of the cost function have been constraine to the output region of the observed data (Evans and Heckman 1984; Palmer 1992). Whil this approach has its appeal, in that no extrapolations are made outside the sample which i used to estimate the cost function, the methodology does not allow for the possibility that a entrant will offer service with a significantly different vector of outputs and network topolog than the incumbent.

In this paper, we use an engineering optimization model to study the long-run cost functio of the local exchange market. The model has as its objective function the selection an placement of facilities in a manner which minimizes the cost of satisfying various marke conditions. Since the model allows us to estimate the cost of stand-alone telecommunication networks, we are able to compare the cost of a single network which is required to carry fou distinct outputs (toll and local switched servces and toll and local private line) with the costs of various combinations of speciality networks. We find that in densely populated markets, there are diseconomies of scope between switched and non-switched services. In all markets, there are strong economies-of-scope between switched services.

2. Data Problems Encountered in Prior Studies

In recent years, as policy makers have considered structural and pricing changes in the telecommunications industry, parties to regulatory and judicial proceedings have presented econometric estimates of the industry's total cost curve. Researchers were initially unable to reach strong conclusions because of the poor quality of data. Working with Bell System data for the years 1947 to 1977, the analysts encountered the problem of how to control for technological change (Christensen, Christensen, and Schoech 1982, 7). The technology during this time period varied greatly. At the end of World War II, manual switchboards constituted fifty percent of the in-service switches owned by the Bell Operating Companies. But by 1977, operators were rarely used to complete calls. Indeed, over twenty percent of the switching machines were computer-controlled electronic switching machines (FCC 1949 and 1979, table 16 and 25). While both research and development expenditures and the number of access lines served by modern switching machines have been used as proxies for technical change, they only roughly control for shifts in the cost curve. If shifts in the cost function are not properly taken into account, biased parameter estimates may result.

The analysts have also had trouble controlling for input prices and constructing output indexes for the various categories of service. Because of these and other data problems, Evans and Heckman (1984) have argued that before conclusive statements about the cost function can be made, new data would have to be located.

In a recent paper (Shin and Ying 1992; hereafter SY), the authors claim that they have "solv[ed] the data problems" (1992, 172). Using data constructed from the Federal Communication Commission's Statistics of Communication Common Carriers, SY use the translog flexible functional form to estimate the local exchange carriers cost function.[2] They conclude that the "cost function is definitely not subadditive," and therefore efficiency gains can be achieved if the local exchange carriers are broken up (1992, 181).

2 Leggette has also used the translog cost function and data from *The Statistics of Common Communication Carriers* to estimate a multiproduct cost function. Leggette concluded that there were not economies of scope between his two outputs, private branch exchange and main station telephones (1985).

While SY make an important contribution to the discussion of the cost structure of the industry, we are not in agreement with their claim that the industry is "indisputable[ly]" (1992, 181) an unnatural monopoly. There are, at a minimum, five flaws with their methodology that cause us to be skeptical about their conclusions.

First, the data source used by SY classifies the firms as local exchange companies. The SY analysis suggests that the output of these firms is limited to customer access, and exchange and toll usage. Many of the firms included in the data set were simultaneously providing such vertical services as private branch exchanges and key systems. Their model specification does not control for variations in these outputs across firms.

Many of the local exchange companies were also providing interexchange services. Bell Operating Companies such as Pacific Telephone, as well as many of the larger independent telephone companies, owned interexchange facilities that were used to transport calls for hundreds of miles. Other carriers, such as Cincinatti Bell and small independent companies, had few interexchange facilities. The local exchange companies which had limited ownership of interexchange facilities handed off almost all toll calls to other carriers. The larger local exchange companies, on the other hand, were actively involved in interexchange transport. Since the large firms were providing interexchange transport service while most of the small firms were not, the marginal cost of a toll call within a large firm would be significantly higher than that for a small firm. The difference in cost is attributable to the varying functions carried out within the firm rather than to the increasing marginal costs of production, all else equal. Since SY do not control for variations in mode of operations between firms, their parameter estimates are likely to be biased (Mundlak 1978).

SY attempt to control for economies of density by using a proxy variable, average loop length (1992, 175). SY calculate average loop length (AL) by dividing the miles of cable by the number of telephones. They propose that, all else equal, density decreases as AL increases. The miles of cable listed in the Statistics of Common Carriers includes the wire used for interexchange, exchange interoffice (between central offices), building cable, as well as the variable of interest, the cable used to connect a central office to the customer's location. For large exchange companies, the proxy for customer density would be biased upward because of the inclusion of building, and interoffice and interexchange cables that are of minimal magnitude for smaller companies.

The level of aggregation used for their capital stock variable is also problematic. SY calculated their real capital stock measurement by dividing capital expenditures by a single communications' equipment price deflator obtained from The National Income and Product Accounts (1992, 174). This index is based on the cost of equipment used inside buildings (Flamm 1988, 30).[3] This index does not take into account changes in the price of outside plant, facilities which account for approximately one-third of the local exchange companies' investment. Since the price trend for outside plant facilities was significantly different than that for inside plant, there is the possibility of inconsistent, biased estimates resulting from the measurement error.[4]

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3 When Christensen, Cummings and Schoech (1981) built the dataset that has been used by prior econometricians, they used different price indexes for each of the primary types of facilities.

4 For example, between 1976 and 1980, the price of outside plant increased by 33%, while inside plant increased by 12% (*Bell System Telephone Plant Indexes*).

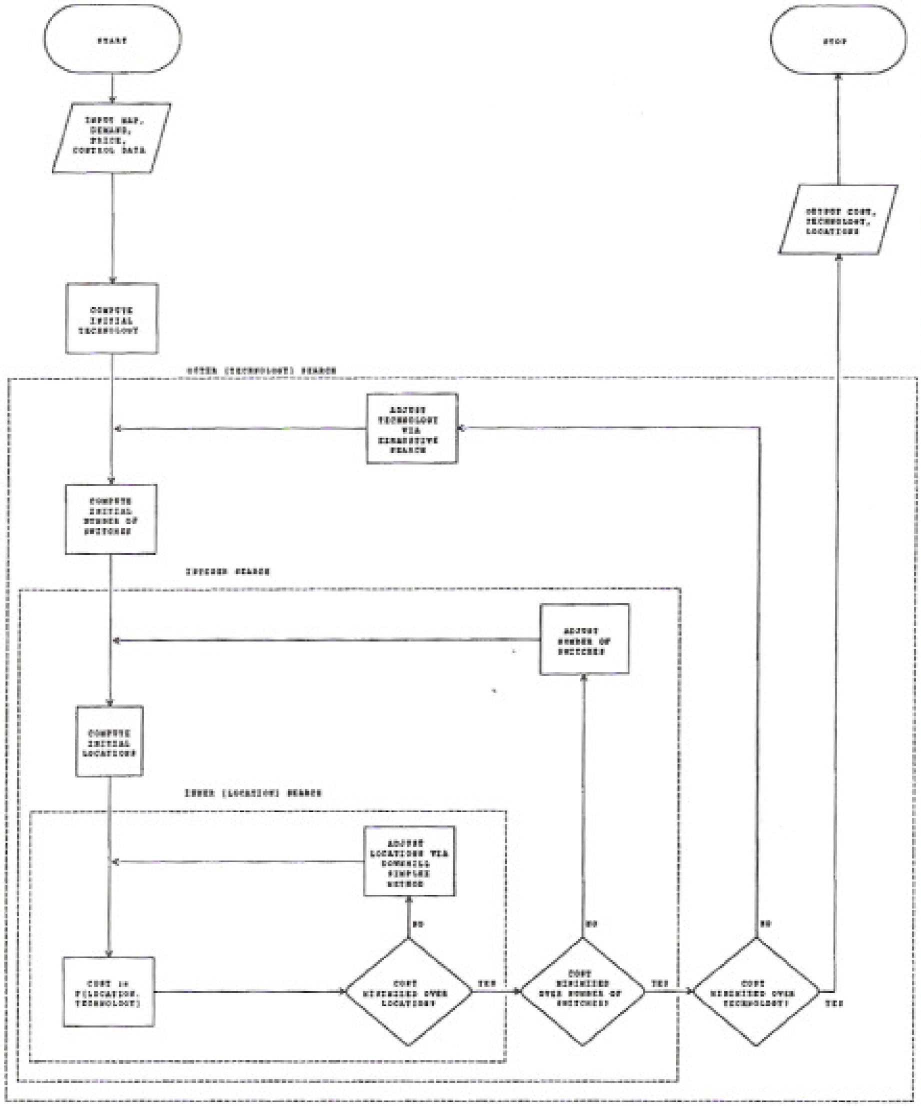

Figure 1. LECOM Flow Chart

Finally, many of the output values constructed by SY to test for subadditivity of the cos function are not plausible. In their test, SY apportion a market's output between firm A anc B. They construct "hypothetical output vectors,

$$q^a = (\kappa q_1^m, \lambda q_2^m, \nu q_3^m)$$

$$q^b = ((1-\kappa)\, q_1^m, (1-\lambda)\, q_2^m, (1-\nu)\, q_3^m),$$

where the scalars κ, λ, and ν = (0.1, 0.2, ..., 0.9)" and q_i, $i = 1, 2$, and 3, refer to access, local and toll calls respectively (1992, 177-78). The cost function is subadditive if

Figure 2. PSEUDO-CODE for the cost function optimized by LECOM

```
Function cost(location_vector, technology_vector, number_of_switches);
BEGIN;

If location_vector has elements outside city limits then
        begin;
                cost := infinity;
                go to end_of_function;
        end;

Attach each remote switch to the nearest host DMS-100 switch;

Adjust the capacity of each DMS-100 switch to account for remotes;

Attach each serving area to the nearest (cheapest) available switch that has not yet
been filled to capacity;

Allow switches to trade serving areas if both switches can thus serve at least as
cheaply;

Allow remote switches to trade serving areas with respective hosts if both can thus
serve at least as cheaply;

Calculate utilization for each switch;

For each DMS-100 switch DO
        begin;
Calculate cost of pinetree feeder network to attached serving areas   (SAs);
                Calculate distribution cost for attached SAs;
                Calculate switching cost;
        end;

For each DMS-10 switch DO
        begin;
                Calculate cost of pinetree feeder network to attached SAs;
                Calculate distribution cost for attached SAs;
                Calculate switching cost;
        end;

For each remote switch DO
        begin;
                Calculate cost of pinetree feeder network to attached SAs;
                Calculate distribution cost for attached SAs;
                Calculate switching cost;
        end;

Compute cost of interoffice trunks;

Compute Main Distribution Frame (MDF) cost;

cost := feeder costs + distribution costs + switching costs + interoffice trunking costs +
MDF cost;

END_OF_FUNCTION;
END;
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$$C(q^a) + C(q^b) > C(q_1^m, q_2^m, q_3^m).$$

During the peak-calling hour, the period which determines most central office capital expenditures, usage per access line is typically in the order of five minutes.[5] Assume that initially q_1, the number of customer access lines in a market, is equal to 100, and usage per subscriber during the peak calling hour is five minutes. SY allow the value of κ to be as low as 0.1, while λ and ν can be as high as 0.9. Under these assumptions, firm a would supply 10 access lines and 450 minutes of usage. This translates to 45 minutes of usage per line. This level of usage is not observed even among the most intense users of switched services, and as a result, switching machines have not been designed to handle such a high load level.[6] Consequently, many of the hypothetical output vectors considered by SY involve network configurations that were not technically feasible during the period of their study.

3. Why an Optimization Model?

The judge who oversaw the 1974 AT&T anti-trust case, Harold H. Greene, concurred with the Department of Justice that it was necessary to monitor and control the activities of the Bell Operating Companies because the local exchange market was a "natural monopoly." Judge Greene concluded that effective competition was not likely to occur in the near future because there were "very substantial economies of scale and scope..."(*US v. Western Electric*, 673 F. Supp. 525, 538 D.D.C. 1987).

SY disagree with Judge Greene's characterization of the cost structure—they conclude that the cost function is superadditive and therefore the industry is not a natural monopoly. But as discussed in the previous section, there are significant data and theoretical problems with their work. We address the issue of economies of scope by analyzing data generated by an optimization model, the Local Exchange Cost Optimization Model (LECOM).

Traditionally, economists have analyzed the cost structure of an industry by observing the relationship between sample observations of input prices, outputs and the cost of production. But because of the data problems encountered in earlier work, we chose instead to study the cost function by working with engineering data. This approach has been used in other industry studies.[7] LECOM was designed to select the combination and placement of facilities in a manner which minimizes the cost of production.[8]

Since the placement and selection of the number of network nodes is endogenous, we use the simulation model to represent the long-run cost function. The simulation involves three steps. First, algorithms were developed that model the production function. Second, the cost-output relationship was derived from the assumed optimization behavior. Here the minimum cost of production is identified for various output levels given 1990 input prices

5 (Rey 1983, 125). In this example, we treat usage as the sum of exchange and toll usage. This simplification does not affect our analysis.

6 "Usage Forecasting by Class of Service," American Telephone and Telegraph System Letter 83-05-128.

7 For example, economists have used process models to study the cost structure of the electric, petroleum, and chemical industries (Griffin 1972 and 1977; Manne 1958; Chenery 1949). Process models identify the cost of expanding output for known facility locations. The process models, unlike LECOM, do not search for the cost minimizing location of facilities.

8 We had to construct the optimization model because no model was available that solved the problem of selecting the combination and location of facilities that minimized the cost of satisfying varying levels of demand (Mitchell 1990, 8).

and the production function.[9] Finally, the information contained in the data set created by the simulation is summarized in a form familiar and useful to an economist or policymaker.

The data generated by the simulation offers some important advantages relative to the data set used in previous studies. As argued by Griffin, "The explicit representation of the technology in the ...[process] model offers particularly important advantages for long-run analysis in which technological and...[policy] changes lie outside the range of historical time series experience" (1977, 391). The model reflects the cost of using state-of-the-art digital technology. The data set used by SY ended in 1983, six years later than the observations used by Christensen, Cummings and Schoech (1983), Evans and Heckman (1983), and Charnes, Cooper and Sueyoshi (1988). The use of more current cost data provides a clearer picture of the cost structure of this rapidly changing industry. Second, much of the research interest in the cost structure of the industry is tied to a concern about the efficiency of entry and competition. In previous econometric studies of the telephone industry, the level of observation has been the firm. The firms included in the data sets have provided service in small towns and large cities. The cost data for different markets has been aggregated into one observation. For example, the largest supplier in New York, New York Telephone, provides service in cities with customer density ranging from under 250 to over 75,000 per square mile.[10] In SY's data set, these heterogenous markets are aggregated into one observation. Since the level of observation is the firm, SY are unable to observe or measure competition in specific markets.[11] Entry, on the other hand, has occurred almost exclusively in densely populated markets. Entrants, such as Teleport, offer service only in the larger, more profitable markets.[12] In order to understand the cost structure of the markets where competition has occurred, it is necessary to have data on the cost of serving cities, or limited neighborhoods such as a city's business district.

4. Mechanics of the Model

In this section of the paper, we briefly describe the mechanics of the optimization model. For a detailed explanation, the reader is referred to Gabel and Kennet (1991).[13]

There are three primary types of facilities found in the local exchange carrier's network: the local loop, switching, and trunking. The local loop is composed of facilities that provide a signalling and voice transmission path between a central office and the customer's station. The central office (or wire center) houses the switching machine that connects a customer's

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9 The cost-minimizing factor mix in a telephone network is determined in a manner similar to a nonlinear transportation problem. That is,

$$C(\mathbf{w},\mathbf{y}) = \min_x \mathbf{w}'\mathbf{x}$$

subject to $A(\mathbf{x}) \geq \mathbf{y}$,

where $\mathbf{w}$ is an n-vector of factor prices, $\mathbf{x}$ is an n-vector of factor technologies, $\mathbf{y}$ is an m-vector of outputs, and A is a mapping from $\mathbf{R}^n$ to $\mathbf{R}^m$ which completely defines all possible paths to produce $\mathbf{y}$ given $\mathbf{x}$.

Note that the objective function $\mathbf{w}'\mathbf{x}$ in the above program is linear. A, however, is nonlinear since a given $\mathbf{y}$ is produced according to a number of nonlinear constraint functions.

10 Response of New York Telephone to User Request #147, Case 28978, New York Public Service Commission.

11 The dataset used by Christensen, Cummings and Schoech (1983), Evans and Heckman (1983), and Charnes, Cooper and Sueyoshi (1988) suffers from the same infirmity.

12 *Network World*, vol. 7, no. 46, pp. 54, 57 (November 12, 1990).

13 As mentioned in the acknowledgements, the program (LECOM) can be obtained at reproduction cost from either co-author.

line to either another customer who is served by the same switch, or to an interoffice trunk. Calls between central offices are carried on trunks.

The model takes as data a city's dimensions and customer usage levels. LECOM then searches for the technological mix, capacity, and location of switches that minimize the annual cost of production. This is equivalent to minimizing the present worth of capital, maintenance, and tax expenditures (Freidenfelds 1978, 821). The locations of the switches are optimized by the non-linear derivative free routine proposed by Nelder and Mead (1965) and described in Press, et al. (1986). The problem solved by LECOM is

$$\min_{\substack{\tau \in T^* \\ S,\, x,\, y}} SC(\tau_s, x, y, S) + TC(\tau_r, x, y, S) + FC(\tau_f, x, y) + DC(\tau_d, x, y) \tag{1}$$

where τ is a vector of technologies available (elements of τ are subscripted s for switching, r for trunking, f for feeder, and d for distribution), T^* is the set of feasible technologies, S is the number of switches employed, x is an S-vector of x coordinates for the locations of the switches, y is an S-vector of y coordinates for the locations of the switches, SC is switching cost, TC is trunking cost, FC is feeder cost, and DC is distribution cost. Note that while S does not enter as an argument into the FC and DC functions, FC and DC do implicitly depend on S since S is the order of the x and y vectors.

Consider the problem of simply optimizing the number of switches. The cost-tradeoff of adding an additional switch to a network is illustrated by equation (2). Imagine that there is only one switch technology available, that the switches can be installed only in specific locations, and that switches come in only one size. Then the control variable is S, the number of switches. The firm will choose an integer value of S that minimizes

$$C(S) = SC(S) + TC(S) + FC(S) + DC(S) = SF_s + ccsV_s + SF_t + V_tTD_t + F_L + V_LLD_L, \tag{2}$$

where:

$C(S)$ = cost expressed only as a function of S, the number of switches
S = number of switches
F_s = fixed cost of a switch
ccs = one-hundred calling seconds during the peak demand period
V_x = variable cost of a ccs
F_t = fixed cost of trunking at a switch
V_t = variable cost per/mile of an interoffice trunk
T = number of interoffice trunks
D_t = average distance per trunk
F_L = fixed cost of loops for a given city size
V_L = variable cost per/mile of a loop
L = number of loops
D_L = average loop length (distance between customer and central office) measured in miles.

In general, the relationships between modular costs and S are:

$\frac{\partial T}{\partial S} > 0$ (number of trunks increases as number of switches increases).

$\frac{\partial D_L}{\partial S} < 0$ (loop length decreases as number of switches increases; even though feeder and distribution cost are not directly functions of the number of switches, they are functions of the locations of those switches).

$\frac{\partial D_t}{\partial S} < 0$ (trunk length decreases as number of switches increases).

The first order condition for solving equation (2) is

$$\frac{\partial C}{\partial s} = F_s + F_t + V_t D_t \frac{\partial T}{\partial S} + V_t T \frac{\partial D_t}{\partial S} + V_L L \frac{\partial D_L}{\partial S} \cong 0.$$ [14]

Because we are only able to consider integer values of S, we cannot set the derivative equal to zero. If the derivative is negative, that is, costs decline when an additional switch is deployed, the switch should be added.

The intuitive explanation of the derivative is as follows: A switch should be added if the additional fixed cost of trunking and switching ($F_s + F_t$), as well as the cost of the additional trunks $\left(V_t D_t \frac{\partial T}{\partial S}\right)$ is less than the savings from shorter loops and trunks

$$\left(V_t T \frac{\partial D_t}{\partial S} + V_L L \frac{\partial D_L}{\partial S}\right)$$ [15]

Figure 1 gives a flow-chart diagram of the doubly-nested optimization that LECOM performs. The innermost loop is a search for locations of switches within the city's 'boundaries' as defined by the data. The intermediate loop is an integer search for the optimum number of switches of a given technology needed to serve the town. The outermost loop is an exhaustive search over technologies. The result of the optimization is the cost-minimizing configuration of switches and their locations, as well as the minimized cost.

Figure 2 gives pseudo-code for the LECOM cost function. In the pseudo-code, we see that equation (1) is integrated into the nested optimizations by declaring cost as a function of technology, number of switches, and location; and it is possible to get a flavor of how the switching, feeder, distribution,and trunking cost modules are integrated.

These modules are fairly complex. For example, the feeder module involves constructing the pinetree route design for feeder cables, which in turn involves sorting the serving areas along each feeder main by distance. The module (like the other modules computing cabling costs) exploits the economies available by bundling cables together, further complicating the optimization. Further, feeder (as well as distribution and trunking) cables are assumed to only follow street grids, which means all distances are L^1 (absolute deviation) norms rather than the more familiar Cartesian distances.

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14 The solution to the first-order condition may result in a non-integer valued number of switches; in this case the exact solution may be the integer on either side of the fractional part, depending on which one gives the lower cost. For example, suppose the analytic solution using derivatives gives us an answer of 4.8. Then the correct integer- valued answer could be either 4 or 5.

15 In performing the requisite optimizations, LECOM is more flexible than the preceding discussion indicates: LECOM will simultaneously optimize the number of switches and the technology of the switches, as well as their location within the city in question.

Another example of the complexity of the modules lies in the switching cost modules. The manufacturer of the switches has developed engineering algorithms that determine the appropriate physical quantities of equipment for various levels of demand. For example, the the number of multiplex loops in the DMS-10 module is a nonlinear increasing function of usage, while the number of line group controllers in DMS-100 computations is equally complex. The number of remote switches attached to the DMS-100 plays another nonlinear role.

These nonlinearities and non-smoothnesses give rise to the need for the derivative- free location-optimizing algorithm mentioned above.

5. Limitations of an Optimization Model

Before providing the cost estimates from LECOM, we briefly address two important limitations of engineering optimization models: the estimation of administrative costs, and bounded rationality.

5.1. Administrative Costs

Optimization models are designed to identify the cost minimizing technical configuration that will satisfy a given level of demand. Typically, optimization models are not designed to quantify the less tangible costs of providing service. The models simulate the physical production process and spend little or no effort measuring marketing and administrative efforts.

For a number of years the telephone companies have been submitting long-run incremental studies to State and Federal Commissions. In response to the charge that their process models did not reflect these overhead costs, the telephone companies have developed loading factors that take into account administrative and marketing expenses. These loadings have been included in our model.[16]

5.2. Bounded Rationality

We have no a priori reason to believe that the cost function is globally concave. Therefore, we do not know if the solution found by our optimization model is a local or global minimum. Since there are an infinite number of possible configurations to be considered, and each proposed solution is costly to evaluate, we limit our research to a reasonable number of possibilities. For each economically and technically feasible combination of switches, we allow for up to 1000 possible iterations. An iteration involves the calculation of the cost of service at one or more alternative locations for the switches.

16 Administrative costs are a linear function of the level of investment. Therefore, the administrative costs will exhibit the same economies or diseconomies that are present in the use of physical facilities. Evans and Heckman raise the issue of whether managerial diseconomies can exceed engineering economies. Because of this concern, they argue that "Although engineering studies may be useful to businessmen choosing between alternative technologies, they are of little use for determining whether an industry is a natural monopoly" (1983, 141). Evans and Heckman express their preference for "hard data" rather than engineering constructs (1983, 141). Unfortunately, the "hard data" provide little or no indication of the industry's current or future cost trends. In order to identify prospective costs in a dynamic, capital-intensive industry, we contend that an optimization model provides more insights than the use of "hard"—but historical—data.

For each market, and a given level of demand, LECOM evaluates a number of different switch combinations. This further increases the number of solutions that are evaluated. Therefore while this search process is not exhaustive, we consider a wide-range of feasible solutions.

6. Is the Local Exchange Market a Natural Monopoly?

An industry is considered to be a natural monopoly if and only if a single firm can produce the desired output at lower cost than any combination of two or more firms. This property, known as subadditivity of the cost function, holds if for any set of goods $N = 1, \ldots n$, and for any m output vectors $Q_1 \ldots Q_m$ of the goods in N (Baumol 1977, 810): $C(Q_1) + C(Q_2) + \ldots C(Q_m) > C(Q_1 + Q_2 + \ldots + Q_m)$.

A necessary, but not sufficient condition for a natural monopoly is economies-of- scope. Economies of scope exists if for some partition $P = \{T_1, \ldots T_m\}$ of S, such that $\cup T_i = S$, $T_i \cap T_j = \varnothing$ for $i \neq j$, $T_i \neq \varnothing$, and $m > 1$, $\sum_{T_i} [C(y_{t_i})] > C(y_s)$ (Panzar 1989, 15-16).[17]

Table 1. Cost of Stand Alone Networks	
Outputs	Cost
x_1,x_2,x_3,x_4	25,549,965
x_1	20,367,226
x_2	18,793,975
x_3	2,313,658
x_4	1,882,234
x_1,x_2	21,553,947
x_3,x_4	3,544,048
x_1,x_3	22,694,392
x_1,x_4	21,467,396
x_2,x_3	20,698,126
x_2,x_4	19,928,418
x_1,x_3,x_4	24,152,641
x_1,x_2,x_4	23,028,627
x_1,x_2,x_3	24,355,382
x_2,x_3,x_4	22,018,534
VOLUME	
x_1 = busy-hour exchange CCS	= 402,530
x_2 = busy-hour toll CCS	= 55,932
x_3 = local private lines	= 17,308
x_4 = toll private lines	= 4,685
access lines	= 157,007

17 Sufficient conditions for a multiproduct natural monopoly are economies of scope and declining average incremental costs. [See Evans and Heckman (1984, 615-16).) Other sufficient conditions for a natural monopoly are discussed by Sharkey (1982, 67-73).

In this section of the paper, we provide data on the extent to which economies of scope are present in the local exchange telecommunications industry. We have assumed that the firm produces four outputs: switched toll and exchange services, and toll and exchange private line services.[18] Let

X_1 = exchange switched service
X_2 = toll switched service
X_3 = local private line service
X_4 = toll private line service.

We have estimated the cost of producing these services in common (i. e., all four services provided through one network), as well as through subsets of the grand coalition. The results for a city with 179,000 customers, spread over 8.12 square miles, are reported on table 1.

In order to determine the extent to which there are economies-of-scope, in table 2, we compare the cost of providing all four services on one network $[C(X_1, X_2, X_3, X_4) = 25{,}549{,}965]$,with the cost of providing the four services on two or more networks (column b).

Table 2. (Dis)economies of Scope

(a)	Stand-alone Cost (b)	Degree of scope economies* (d)
C(1) + C(2,3,4)	42,385,760	0.658936
C(2) + C(1,3,4)	42,946,616	0.680887
C(3) + C(1,2,4)	25,342,285	-0.008130
C(4) + C(1,2,3)	26,237,616	0.026914
C(1) + C(2) + C(3) + C(4)	43,357,093	0.696953
C(1,2) + C(3,4)	25,097,995	-0.017690
C(1,3) + C(2,4)	42,622,810	0.668214
C(1,4) + C(2,3)	42,165,522	0.650316
C(1,2) + C(3) + C(4)	25,749,839	0.007823
C(1,3) + C(2) + C(4)	43,370,601	0.697482
C(1,4) + C(2) + C(3)	42,575,029	0.666344
C(2,3) + C(1) + C(4)	42,947,586	0.680925
C(2,4) + C(1) + C(3)	42,609,303	0.667685
C(3,4) + C(1) + C(2)	42,705,249	0.671441

*Values greater than zero indicate economies-of-scope and values less than zero indicate diseconomies-of-scope. Values are computed according to the formula $d = [(b - c)/c] - 1$, where b is the sum of the cost of stand-alone networks and c is the cost of providing all services jointly [25,549,965].

The first row of table 2 shows that the total cost of providing exchange service (1) on one network, and switched toll and private line services (2,3,4) on a second network, is 42,385,760 (20,367,226 + 22,018,534). The cost of providing the four services (1,2,3,4) on one network was 25,549,965. The ratio appearing in column d is greater than zero. When

18 Whenever toll or exchange switched service is provided, the customer is connected to the switch via an access line. While this cost is included in the tables below, it is not listed as a product because it is not a service that would ever be provided on a standalone basis.

this ratio is greater than zero, economies of scope are present. This indicates that it is more expensive to construct two networks, then to provide the four services on one network. In two of the combinations appearing on table 2, the value in Column (d) is less than zero and therefore there are diseconmies of scope. The absence of economies-of-scope is due to the trade-off between longer loops and interoffice trunking. When switched exchange or toll service is offered, costs are minimized by housing switching at more than one location. While this increases the cost of interoffice trunking, it provides significant savings in loop costs.

The optimization model determined that if all services were offered on one network, cost would be minimized by providing service through four different offices. For a stand-alone private line system, LECOM determined that cost would be minimized by having all loops terminate at one wire center.[19] For the stand-alone private line systems, the additional trunking costs made it inefficient to establish more than one office. When private line services are offered on a common network with switched services, extra trunking costs are incurred (because of the need to use interoffice trunking to connect local private line customers who are served by more than one central office). This additional cost is the primary source of diseconomies-of-scope.

For the data reported on table 2 there were 22,037 customers per square mile. As indicated on table 3, this is in the range of customer density found in high density residential neighborhoods and is considerably lower than the number of customers per square mile found in high density business districts.

Table 3. Customer Density per Square Mile

Type of Neighborhood	Density per Square Mile
Single-family	2,560 - 3,840
High Density Residential (high rise apartments)	20,480 - 49,960
Office Park	7,680 - 10,240
Industrial Park	1,280 - 11,536
Medium Density Business	5,120 - 7,680
High Density Business	153,600 - 179,200
Commercial Strip (Linear Mile)	614

Source: Gabel and Kennet (1991)

Table 4 provides summary information for a range of city sizes and usage levels. In column (a) we report customer density per square mile. In column (b) we report the degree of economies-of-scope. Columns (f) through (g) identify the level of output. Values greater than zero indicate economies of scope and values less than zero indicate diseconomies-of-scope. The reported values are the minimum and maximum values of the different output combinations identified on table 2.

In low density markets, cost savings are achieved by having everyone share the fixed cost of production. In these markets, economies of scope are present, and therefore the necessary condition for a natural monopoly is satisfied.[20]

19 No switching costs are incurred with an all private line system (i.e., $F_s = 0$).

20 We have not tested for the sufficient conditions of a natural monopoly.

Table 4. (Dis)Economies of Scope

customers per square mile* (a)	Degree of Economies of scope: minimum/ maximum (b)	Exchange CCS (c)	Toll CCS (d)	Local Private Line (e)	Toll Private Line (f)	Access Lines (g)
2,772	0.09/0.81	266,924	62,367	13,611	7,169	101,437
3,419	0.06/0.82	502,434	110,141	21,337	7,265	183,438
4,052	0.08/0.82	411,750	68,817	15,395	8,289	154,348
4,889	0.07/0.94	415,645	57,216	5,392	2,596	146,984
5,994	0.08/0.81	938,338	204,583	27,250	7,375	309,371
8,199	0.01/0.74	402,354	55,908	17,308	4,685	157,007
22,037	-0.02/0.70	402,530	**55,932	17,308	4,685	157,007
25,323	0.01/0.74	411,750	68,817	15,395	8,289	154,348
170,060	-0.02/0.70	402,530	55,932	17,308	4,685	157,007

* [local private lines + toll private lines + access lines] / square miles

** Data also appear in table 1.

These economies dissipate as the customers per square mile increases to the level associated with high density residential communities (more than 20,000 customers per square mile). In two of the three densely populated markets that we studied, the degree of economies of scope is less than zero. The results from the optimization model indicate that cost savings are achieved by having separate networks for switched and non-switched (private line) services. The separate networks for switched and private line services could be run by either an existing local exchange carrier or an entrant.

7. Do the Results Comport with Recent Developments in the Industry?

The results reported in table 4 suggest that the likelihood of entry increases with customer density. This is consistent with recent trends in the industry. Entry has occurred in the high density markets. Entry could be the result of one or both of the following factors. First, in high density markets, the distance between the customer and the telephone company's office is relatively short compared to less dense markets (New England Telephone 1986, book 1, p. III.E.1.19). The cost of connecting a customer to the office increases with distance. If the lower cost of providing connections on short routes is not reflected in the rates, subscribers in densely populated markets may be charged a rate that exceeds the cost of service. The supra-competitive price would attract entry.

An entrant may also be attracted to a densely populated market because of the diseconomies of scope that have been estimated by LECOM. The number of nodes on a network is determined by the number of customers served and the size of the service territory. In densely populated markets, the incumbent telephone companies provide service through multiple locations.

Entrants have found that since they serve a fewer number of customers than the incumbent, and provide almost exclusively non-switched services (X_3, X_4), production costs are minimized by constructing a network with fewer nodes. For example, while New York Telephone serves the area of Manhattan south of 96th Street with switching machines at over 15 locations, an entrant, Teleport, serves the same territory with just one node.[21]

Parenthetically, we note that the incremental cost estimates derived from LECOM (Gabel and Kennet 1991, 61-67) are in line with those of Mitchell (1990) and estimates made by the industry (New England Telephone 1986).[22]

8. Economies of Scope With Switched Services

SY evaluated the cost of providing access, and switched toll and exchange services. In this section of the paper, we use the data from our optimization model to evaluate the degree of economies of scope for the same switched services. The data reported on table 5 indicates that the degree of scope economies between toll and exchange service is in the order of 0.8 for a large range of customer densities.

To a large degree, these economies of scope arise from the public input nature of the local loop. Panzar defines a joint good as an input "[t]hat is, once acquired for use in producing one good, they (sic) are costlessly available for use in the production of others" (1989, 17).

Local and toll usage on an access line during the peak hour is in the order of five minutes (Rey 1983, 125). Once the loop is installed for service a, the additional cost of providing service b over the same facility is zero.[23] If, on the other hand, local and toll services are provided on separate networks, the non-trivial cost of the loop is duplicated. In light of these intuitively clear strong economies of scope that derive from the shared use of the local loop, we are skeptical about SY's finding that for the products access lines, toll and exchange calls, the cost function is superadditive.

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21 New York Telephone, response to information request CPBCS 199, in Docket 28978, New York Public Service Commission.

22 For example, Mitchell estimates that the cost of an access line is the sum of three components: $53 to $66 for the feeder and switch termination, and $45 for the distribution plant (1990, 46-47). His loop cost estimate, approximately $104.5, was based on the assumption that 40,000 customers were attached to a switch and the number of customers per square mile is *greater* than 2500 (1990, 20, 36). Mitchell does not indicate the actual density value; instead, he only provides the lower bound of 2500). Our baseline case reported in tables 1 and 2 is based on the assumption of 22,037 customers per square mile. LECOM determined that the 157,007 switched access lines should be served by four switching machines. This leaves us with an average number of customers per switch that is similar to the value used by Mitchell, 39,252. For this size city, LECOM estimated that the incremental cost for access was $112.69 (Gabel and Kennet 1991, 64). For the same city, we estimate that the cost of a toll call that goes through a tandem is $20.21 per busy-hour CCS (1991, 64). Depending on the type of facilities used, Mitchell reports a cost of between $8 and $35 per busy-hour CCS (1990, 54). Note, though, that the results are not strictly comparable because Mitchell excludes costs from his estimate of the marginal cost of a toll call items that are included in LECOM (e.g., line-haul costs) (Mitchell 1990, 39-40, 75). Due to the different assumptions on the percentage of exchange calls that originate and terminate on the same switch, it is not possible to compare our estimate of exchange usage costs with Mitchell's; private line service estimates are also not comparable since Mitchell does not estimate the cost of private line service.

The NET study does not identify costs by customer density. Instead, it provides the cost by customer rate-band. NET concluded that the incremental cost of terminating an access line ranges from $69 to $156 per year (1986, Book 1, Tab 2, p. 11 of 15; and Book 1, Tab 1, p. 19 of 19). These values are consistent with those reported by Gabel and Kennet (1991, 61-67). Because of the wide variation in the type of calls and private line services reported in the NET study, it is difficult to compare the study's incremental cost estimates for toll and private line services with those of LECOM.

23 Within the industry, the cost attribute usually used to describe the loop is non-traffic sensitive plant. The nomenclature reflects the lack of congestion in the local loop.

Table 5. Economies of Scope for Switched Services

customers per square mile*	Degree of Economies of Scope**	Exchange CCS	Toll CCS	Access Lines
2,301	.74	266,924	62,367	101,437
2,958	.81	502,434	110,141	183,438
3,513	.82	411,750	68,817	154,348
4,637	.78	415,645	57,216	146,984
5,390	.81	938,338	204,583	309,371
7,191	.81	402,354	55,908	157,007
19,322	.82	402,530***	55,932	157,007
21,954	.78	411,750	68,817	154,348
149,165	.82	402,530	55,932	157,007

* access lines square miles

** Values greater than zero indicate economies-of-scope and values less than zero indicate dis-economies-of-scope.

*** Data also appear in table 1.

9.Conclusion

The results from LECOM are consistent with the evolution of the industry. Prior to 1890, local and toll calls were completed through separate exchange networks. AT&T found that there were strong economies-of-scope from combining these two services in one exchange network.[24] More recently, the local exchange companies have faced their strongest competition in the private line market. There has been little entry into the switched exchange market. This reflects, along with higher regulatory barriers to entry in the switched market (NTIA 1988), the economies of scope for switched services identified herein.

One policy implication of this study is that there is a need for regulatory oversight of the incumbents' pricing of private line services. At times when faced with entry, the local exchange companies have adopted rates that were based on the cost structure of their competitors (Temin 1990, 353). If the incumbents continue to use one network for both switched and non-switched services, regulatory commissions should set the incumbents' rates for private line services based on the marginal cost of production of the existing network architecture.

While there are diseconomies of scope in part of the local exchange market, our research departs from SY in our measurement of the magnitude. We do not find that there are "considerable" (SY 1992, 181) diseconomies of scope. Consequently, the larger gains from competition are more likely to arise from the dynamic incentives of rivalry, rather than static diseconomies of scope.

24 Memorandum from T. Sheridan to J. Hudson, November 20, 1895, box 1275, American Telephone and Telegraph Corporate Archive.

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