service category are deflated by Bell System price indices found in Christensen, et al.[20]

Output growth is measured by deflated revenues or a Divisia index of the seven real revenue categories because no simple physical output index is satisfactory. The usual approach to measuring output in this industry is to combine some measure of minutes of use with total access lines. However, this approach fails to capture changes in carrier output such as an increase in directory advertising, a shift towards longer or shorter calls, a change in the temporal pattern of calls, the detariffing of terminal equipment, or the phasing out of inside wiring.[21] As a result, an index of output changes must be constructed to capture changes in the value added in each service category, and deflated revenues achieve such a purpose. Unfortunately, even a Divisia index of real revenue categories depends importantly upon the accuracy of the deflators and the homogeneity of service categories.

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20. See fn. 14, above.

21. The latter two changes are particularly important. Beginning in the late 1970s, subscribers could attach their own equipment to their access lines. In 1984, terminal equipment was detariffed, and most customers changed to owning their own instruments. In addition, new subscribers in new homes or businesses were forced to pay for their inside wiring beginning in 1981. Thus, the provision of "local service" changed dramatically in the 1980s in ways that would not be captured by data on minutes of use or access lines.

The Divisia indexes of output growth are weighted by simple nominal revenue shares and by revenue shares adjusted for regulatory distortions. The former approach is utilized by Christensen, et al., on the assumption that rates are proportional to marginal costs of service. Unfortunately, we know that regulators distort rates significantly, particularly between toll and local service, but the degree of distortion is difficult to measure. In this paper, we adjust revenues for the estimated shift of local-service costs to toll services. For this adjustment we first estimate the amount of non-traffic-sensitive costs assigned to interstate calls from historical sources[22] and from the Federal Communications Commission. This amount is deducted proportionately from interstate WATS and MTS revenues and added to local revenues after first deducting those NTS costs recovered through federally-imposed subscriber line charges. Lacking detailed data on intrastate distortions, we assume that intrastate toll rates were distorted to the same degree as interstate calls until the early 1980s, but that the degree of distortion fell less rapidly than in the interstate jurisdiction, given the slower real rate of decline in intrastate rates in the 1980s.

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22. Specifically, we utilize Carol Weinhaus and Anthony Ottinger, Behind the Telephone Rate Wars, for AT&T data on NTS costs for the 1970s and extend this series using data from the Congressional Budget Office, op.cit.

An adjustment to real revenues is required for the period after 1984 to eliminate double counting due to access charges and local-exchange company revenues for billing and rental payments from long-distance carriers. Access charges are eliminated from AT&T and OCC revenues because this source of value added should properly be attributed to the local exchange companies. In addition, the local carriers record as "miscellaneous" revenues charges to the long-distance carriers for billing and rental revenues. These sources of revenues are reassigned from miscellaneous to long-distance services and deducted from long-distance carrier revenues.

Inputs are divided into labor, capital, and all other, or "materials." The labor series is constructed from FCC, USTA, and company data on employment, multiplied by average weekly hours in SIC 481 as reported by BLS, and then adjusted for changes in labor-force composition per Christensen, et al.[23] Capital services are assumed to be proportional to the capital stock which is constructed from real investment flows for all telecommunications carriers as reported by the FCC, USTA, and the companies. Straight-line depreciation[24] and

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23. See fn. 14. This procedure was followed for 1960-79. For 1980-88, an estimate of the quality adjustment factor was obtained from forecasts from a regression of the quality adjustment factor on real telephone industry wages for 1960-79.

24. In addition, a measure of net capital stock based upon declining-balance depreciation was calculated. The estimates of TFP are somewhat lower with the net capital stock estimates based upon declining-balance depreciation, but none of the qualitative results

discard rates are drawn from BEA's Fixed Reproducible Tangible Wealth in the United States. Capital services are adjusted for the detariffing of terminal equipment in 1984. Materials cost is simply the accounting cost of all other inputs used in the current production of telecom services deflated by the GNP deflator.

The share of each input in current costs is calculated from the FCC, USTA, and annual company reports of accounting data. Materials cost is a residual, calculated by deducting total labor compensation for current production and capital income from revenues (exclusive of access charges and gross receipts taxes). For the entire 1960-88 period, the shares of capital, labor, and materials average 0.43, 0.34, and 0.23, respectively. Using a different approach, Christensen et al. calculate average shares for 1961-79 of 0.50, 0.37, and 0.13, respectively.[25]

Data were collected for 1960 through 1988, the most recent year for which all data are available. Details of the output and input series calculations may be found in an Appendix available from the authors.

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or trends are affected by using declining-balance rather than straight-line depreciation.

25. Part of the difference between our weights and Christensen, et al. derives from our inclusion of the post-1984 period in which the industry has become more vertically fragmented. In addition, we analyze the entire industry while Christensen's analysis is focused entirely on AT&T.

Productivity Estimates

The resulting estimates of TFP are shown in Tables 1 and 2 for the entire telecommunications sector and its major subgroups.[26] The results are shown as simple averages of the Tornquist-weighted annual rates of 3-factor TFP growth over various subperiods.[27] The results for the OCCs are presented only for the 1980s since they were only marginal participants in the industry in the 1970s. For the rest of the industry, the results are divided into several subperiods, reflecting the dates of various policy changes in the industry.

In the 1961-70 period, the industry was a set of virtual monopolies. Competition did not exist in terminal equipment nor in long-distance. In the 1971-83 period, competition developed in both markets as the FCC admitted new long-distance carriers and forced state authorities to allow customers to connect their own telephones, key sets, PBXs, answering machines, and other equipment to their lines. The 1984-88 period is the period after AT&T was forced to divest itself of its Bell operating companies.

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26. All of these estimates are calculated in terms of discrete annual rates of change rather than the differences of the logarithms of the variables.

27. The reader is reminded that these estimates overstate TFP, as conventionally defined, if there are increasing returns to scale, by a factor of $1 - 1/e_s$ where e_s is a weighted average of the economies of scale in this sector.

Table 1. Estimated Annual Average Total Factor Productivity Growth in U.S. Telecommunications Using Total Deflated Real Revenues for Output, 1961-88 (percent)

Period	Total Sector	Bell System	Independent Phone Cos.	New Long-Distance Carriers(OCCs)	Telegraph Companies
1961-70	2.98	2.92	3.45	N.A.	4.55
1971-80	4.14	4.19	3.97	N.A.	3.41
1971-83	3.80	3.91	3.31	N.A.	2.02
1981-88	3.46	3.07	4.39	4.29	2.54
1984-88	3.94	3.13	6.36	4.56	5.63

Source: See text.

Table 2. Estimated Annual Average Total Factor Productivity Using Divisia Output Indexes, 1961-88 (percent)

Period	Total Sector	Bell System	Independent Phone Companies	New Long-Distance Carriers (OCCs)
USING ACTUAL REVENUE SHARES AS WEIGHTS				
1961-70	3.09	3.07	3.39	--
1971-80	3.92	3.98	3.72	--
1981-83	2.55	2.93	1.10	--
1981-88	2.65	2.39	3.57	3.52
1984-88	2.71	2.07	5.06	3.70
USING ADJUSTED REVENUE SHARES AS WEIGHTS				
1961-70	2.70	2.69	2.91	--
1971-80	3.40	3.53	2.93	--
1981-83	3.06	3.31	2.36	--
1981-88	0.98	0.88	2.13	--
1984-88	0.41	-0.16	3.14	--

Table 1 provides the estimates of TFP growth using the summed real revenues as the output index. These results show a general upward trend in TFP growth in all sectors except the Bell System. The Bell results turn down in the 1980s while independents and other carriers show a continued acceleration in TFP growth. In 1984-88, the entire sector evidences TFP growth that is about the same as in the 1970s despite the AT&T breakup.

The results based upon the Divisia output growth indexes are shown in Table 2. In general, these results show lower TFP growth because the Divisia-weighted indexes of output growth are consistently below those that are based upon summed real revenues. Once again, the performance of the Bell System companies in the 1980s severely depress the sector average TFP growth. For instance, the results based on straight revenue-share weights show a decline in TFP growth for the entire sector from 3.9 percent in the 1970s to 2.7 percent growth in the 1980s, but the Bell System TFP growth declines from 4.0 percent to 2.1 percent between these periods.

Adjusting the revenue-share weights for rate distortions reduces the TFP growth estimates even further because it shifts the weights from the rapidly-growing market for MTS to the slow-growth local access/exchange market. This shift is substantial, increasing the

local share by 14 percentage points. As a result, the growth in TFP for the entire sector slows to less than 1 percentage point in the 1980s. Once again, this deceleration is entirely due to the Bell System results. Independents' TFP continues to accelerate in the 1980s and, because they offer no local service, OCC results are not affected.

The earlier study of Christensen, et al. utilized a somewhat different methodology in constructing inputs and outputs for the Bell system through 1979.[28] Despite these differences, our results are quite similar to theirs. For the 1961-79 period of commonality between their study and ours, we find that the average annual rate of TFP growth for the Bell system is 3.4 percent using the revenue-share weighted Divisia index and 3.0 using the Divisia index with weights adjusted for rate distortions. Their study found an average TFP growth of 3.3 percent over this period.[29]

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28. Christensen, et al., had more input categories and used a Divisia output index using revenue-shares as weights.

29. Philip Schoech of Christensen Associates has suggested to us that our estimates for independents' TFP growth in the 1960s and 1970s may be biased upward because we assume that the price of local service increased at the same rate in markets served by Bell Companies and markets served by independents. Christensen, et al., concluded that independent local rates must have risen more rapidly during the period they analyzed. Unfortunately, there are no continuous price series for independents' local rates. Moreover, the available data suggest that local revenues per access line rose less rapidly for independents than for Bell companies in the 1975-83 period. (Access line data are unavailable for the years prior to 1975).

A Closer Examination of the Trends

The results in Tables 1 and 2 are consistent with one's intuition about recent technological and competitive developments. TFP growth accelerated in the 1970s with the electronics revolution and the entry of new competition into long-distance and terminal equipment. TFP growth slowed in the depressed early 1980s, continued slow for the erstwhile AT&T family in 1984-85 due to divestiture, but has begun to grow rapidly once again since 1985.

A major driving force behind these trends is the effect of demand and its impact on output growth. Communications common carriers have a public service responsibility and cannot adjust rates to ration demand during cyclical swings. Instead, they must maintain a sufficient cushion of capacity to serve surges in demand, and they obviously cannot adjust capital and labor quickly to downturns. As a result, year-to-year changes in demand will have a noticeable effect on estimated TFP.

In the 1970s, output for the telecommunications sector grew at more than 8 percent per year. In the 1980s, growth has slowed to between 2.1 and 4.7 percent according to our estimates (Table 3). Given the substantial changes in telecommunications service offerings and the repricing of service, there is a possibility that BLS has had more than

Table 3. Alternative Measures of Annual Growth Rates in Telecommunications Sector Output, 1961 - 1988 (percent)

Period	Deflated Revenues	Divisia Index Unadjusted	Divisia Index Adjusted	Access[a] Lines	Local[b] Calls	Subscriber[c] Line Usage
1961-70	8.2	8.2	7.8	3.7	5.5	N.A.
1971-80	8.3	8.0	7.5	3.1	5.1	N.A.
1981-88	4.7	3.8	2.1	2.7	3.6	3.9

Source: [a] - USTA, Telephone Statistics, 1988; FCC, Statistics of Communications Common Carriers, annual editions. For years prior to 1975, estimated by the number of main telephones.

[b] - FCC, Statistics of Communications Common Carriers, annual editions; excludes 1983-84 growth due to FCC reporting changes.

[c] - FCC, Common Carrier Bureau, Industry Analysis Division, Monitoring Report.

N.A. = Not available.

the usual difficulty in measuring the PPIs for telephone services accurately and therefore that our output measures are less accurate in recent years. It is also possible that private networks and private ownership of CPE have severely reduced telco growth in the 1980s. The available data on access line growth and the growth in network use (shown in Table 3) seem to evidence a similar pattern, suggesting that whatever the cause, our evidence on the slowdown of telco growth is correct. Unfortunately, even the data on network minutes of use or calls are notoriously inaccurate and inconsistent over time. For this reason, we have not even attempted to construct alternative output measures based upon these physical units.

In order to draw more definitive conclusions about the effects of competition, we must separate the 1984-85 disruptions (from the AT&T divestiture) and the decision of the FCC to admit entry into interstate markets from year to year changes in output. For this purpose, we use two time trends and a dummy variable for 1984-85. As competition increased throughout the 1970s and early 1980s, regulated telecommunications carriers should have been shocked from any regulated-monopoly apathy in the early 1970s and could be expected to have begun to anticipate future threats immediately after the 1971 FCC decision to admit specialized carriers.[30] Therefore, we use both a

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30. MCI was admitted in 1969, but the FCC's decision to open private-line markets to competition on a wider basis did not occur until 1971.

simple time trend, TIME, for the entire 1961-88 period and one that begins in 1972, TIME72. A variable, D84-85, captures the disruptive effects of divestiture. The rate of growth in output (deflated revenues or the Divisia indexes) is denoted DQ.

To examine the impacts of growth, competition, and divestiture, we simply estimate:

$$(4)\ TFP_t = a_0 + a_1 DQ_t + a_2 TIME_t + a_3 TIME72_t + a_4 D84\text{-}85_t + u_t$$

where TFP_t is our estimate total factor productivity growth in year t for the entire sector, the Bell System, and the independents. The results are shown in Tables 4 and 5. In each case, the post-1971 time trend markedly outperforms the simple 1961-88 trend, suggesting that productivity accelerates only after 1971 when the FCC begins to admit competitors.[31] Divestiture has a devastating effect on Bell System productivity in 1984-85, but not on independents' TFP growth. In every case, TFP growth appears to accelerate by between 0.1 and 0.2 percent per year, an acceleration that continues unabated through 1988 after

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31. The 1972-88 trend variable is superior to other nearby alternatives, such as one for 1970-88 or 1971-88, in terms of the goodness of fit of the equation.

Table 4. Regression Estimates of TFP Growth in U.S. Telecommunications, 1961 - 1988, Using Deflated Revenues for Output Index (t-statistics in parentheses)

Productivity Growth in:	Estimated Coefficient: DQ	TIME	TIME(72)	D84-85	$\bar{R}^2$	DW	ρ
Entire Sector	0.37 (2.93)	-0.02 (0.19)	0.22 (1.43)	-2.15 (1.60)	0.362	2.113	-0.134
Entire Sector	0.37 (3.00)		0.19 (3.77)	-2.15 (1.63)	0.388	2.110	-0.133
Bell System	0.34 (2.39)	-0.03 (0.02)	0.20 (1.07)	-2.92 (1.83)	0.323	2.062	-0.113
Bell System	0.34 (2.48)		0.19 (3.16)	-2.92 (7.87)	0.449	2.062	-0.114
Independents	0.55 (5.70)	-0.47 (0.49)	0.32 (2.33)	1.20 (1.04)	0.657	2.028	-0.280
Independents	0.56 (5.93)		0.26 (5.04)	1.26 (1.13)	0.653	1.991	-0.281

Table 5. Regression Estimates of TFP Growth in Telecommunications, 1961-88, Using Divisia Output Indexes (t-statistics in parentheses)

	Estimated Coefficient					
	DQ	TIME(72)	D84-85	$\bar{R}^2$	DW	ρ
UNADJUSTED REVENUE-SHARE WEIGHTS						
Entire Sector	0.31 (2.41)	0.14 (2.63)	-2.56 (1.96)	0.337	2.058	-.107
Bell System	0.29 (2.01)	0.14 (2.23)	-3.34 (2.13)	0.337	2.024	-.096
Independents	0.54 (5.38)	0.22 (4.07)	1.10 (1.01)	0.515	1.944	-.274
ADJUSTED REVENUE-SHARE WEIGHTS						
Entire Sector	0.31 (2.83)	0.11 (2.24)	-4.43 (3.27)	0.691	2.080	-.204
Bell System	0.31 (2.58)	0.12 (2.22)	-5.16 (3.14)	0.683	2.091	-.229
Independents	0.56 (4.79)	0.20 (3.17)	0.45 (0.36)	0.520	1.823	-.173

the effects of the 1984-85 adjustments for the erstwhile Bell System are taken into account.[32]

When we look at the recent changes in input growth in the industry, a further conclusion emerges. The slow growth of output in the early 1980s and the subsequent AT&T divestiture has led to a substantial reduction in labor inputs and a major slowdown in capital formation (Table 6). The adjustment in the labor force obviously has been a protracted one that began before divestiture but continued through 1988. Capital inputs also continue to increase at about half of their 1970s rate because of regulatory decisions. Most carriers are no longer allowed to own and lease terminal equipment through their regulated operations. Inside wiring is now expensed, not capitalized. Private networks are flourishing because they are now allowed to lease bulk lines from carriers or even to build their own transmission facilities, resell service to others, and attach their own equipment to these lines. Nevertheless, despite the slowdown in output growth and capital formation, TFP growth continues in this sector. If the economies of scale and scope were very great, we should have expected to see a slowdown in 1980s TFP growth because of our failure to adjust

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32. All of these results continue to hold for the TFP growth estimates based upon Divisia output indexes with revenue shares as weights although the absolute rates of TFP growth using these Divisia output indexes are lower than those reported above. For the 1986-88 period, TFP growth averaged 4.4 percent using the revenue-share-weighted Divisia output index and 3.1 percent using adjusted revenue shares as weights.

Table 6. Average Annual Growth in Capital and Labor Services in the Telecommunications Sector, 1961 - 1988 (percent)

	CAPITAL SERVICES		
Period	Total	Bell System	Independents
1961-70	6.7	6.2	9.7
1971-80	5.5	5.2	6.6
1981-88	2.3	1.6	2.9
	LABOR SERVICES		
1961-70	2.7	2.7	5.1
1971-80	2.2	2.0	4.0
1981-88	-3.7	-5.0	-1.4

the rate of change of output by the elasticity of costs with respect to output. Our results are consistent to Waverman's[33] and Heckman-Evans[34] and Heckman's skeptical view of the econometric estimates that suggest large economies of scale and scope.

A final caveat is in order. All measures of TFP, whether from econometric estimates of the production (or cost) function or the growth-accounting approach, require a measure of the price of capital services. The deflator for telecommunications equipment used in this study and virtually all others of the U.S. telecommunications sector is based in large part on the Bell Telephone Plant Index (TPI) until 1985 and is tied only to switchgear for 1985-88. Unfortunately, the Bell TPI, like many deflators, has been criticized for not capturing quality improvements in equipment between generations of switchgear, transmission equipment, or terminal equipment.[35] If the BEA deflator for equipment is biased upward over time, as seems likely, the rate of growth of the capital stock will be understated and TFP growth will be

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33. Op.cit.

34. David S. Evans and James J. Heckman, "A Test for Subadditivity of the Cost Function with an Application to the Bell System," American Economic Review, September 1984, pp. 615-23; and "Erratum," September 1986.

35. Kenneth Flamm, "Technological Advance and Costs: Computers Versus Communications," in Robert W. Crandall and Kenneth Flamm (eds.), Changing the Rules: Technological Change, International Competition, and Regulation in Communications. Washington, DC: The Brookings Institution, 1989, pp. 29-35.

overstated in our results. In a sense, this is not a problem because it attributes improvements in equipment to the entire telecommunications sector. Indeed, liberalization and divestiture may have placed pressure on equipment suppliers (including AT&T) to improve product quality more rapidly, thereby increasing the rate of decline in costs due to embodied technical change. We may like to know whether these forces had greater impact within the equipment industry or the services sector, but the value of the social benefit of competition are not affected by their locus.

Comparison with Other Estimates of TFP Growth

We have already seen that the estimates in Tables 1 and 2 for the Bell system track Christensen, et al.'s earlier study very closely. But how do they compare with more recent studies of TFP growth? Table 7 summarizes recent estimates of TFP growth in the overall economy, communications, and various firms.[36] These estimates have been prepared by both government agencies and private organizations.

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36. Excluded from this survey are two recent unpublished papers that utilize econometric estimation of translog cost functions: Tae H. Oum, "The Effect of Competition in the Public Long-Distance Telephone Market on the Productivity of the U.S. Telephone Industry," The University of British Columbia, August 1990; and John S. Ying and Richard T. Shin, "Costly Gains to Breaking Up: LECs and the Baby Bells," The University of Delaware, October 1989. Both papers fail to adjust for the detariffing of terminal equipment and the billing and lease revenues derived by some

Table 7. Recent Estimates of Average Annual TFP Growth (%)

Period	BUREAU OF LABOR STATISTICS[a] U.S. Manu-facturing	U.S. Electrical & Electronic Equipment	AMERICAN PRODUCTIVITY CENTER[b] U.S. Private Business Economy	U.S. Manu-facturing	U.S. Communi-cations	BELL CANADA[c] Bell Canada
1961-70	1.2	2.5	2.1	2.0	3.5	4.2
1971-80	0.8	2.2	0.7	1.5	2.8	3.9
1981-87	1.8*	2.2*	1.2	3.2	2.3	4.1*

	E.E. SUBISSATI[d] British Telecom	FCC[e] AT&T
1985-88	3.8	(1/84-1/88) 2.5

* 1981 - 1986.

a - Bureau of Labor Statistics, Office of Productivity, unpublished estimates.

b - American Productivity Center, Multiple Input Productivity Indexes, Vol. 8, 1988.

c - Bell Canada data.

d - E.E. Subissati, "Some Evidence Regarding British Telecom's Performance Under Price-cap Regulation" paper presented at Bellcore/Bell Canada Conference on Telecommunications Costing in a Dynamic Environment, April 5-7, 1989.

e - FCC, Further Notice of Proposed Rulemaking, CC Docket No. 87-313, May 23, 1988, Appendix C.

The most comprehensive studies of U.S. total factor productivity estimates were those produced by the Bureau of Labor Statistics and the American Productivity Center (APC). The BLS estimates are for five factors -- capital, labor, energy, purchased materials, and business services -- while the APC estimates are based on capital and labor inputs.

The BLS TFP estimates have been calculated only for manufacturing industries. They show a decided slowdown in TFP for all manufacturing in the 1970s and a rebound in the 1980s (Table 7). For SIC #36, Electrical and Electronic Equipment, which includes telephone apparatus, the BLS estimates show less of a slowdown in the 1970s, but no rebound in the 1981-87 period.

The APC estimates evidence a similar, but more pronounced downturn for the entire private U.S. business economy in the 1970s, but a greater growth in TFP for all manufacturing than in the BLS estimates. For U.S. communications, which includes telecommunications and broadcasting, the APC estimates show a general slowdown in productivity growth since the 1961-70 period. This may be due to the difference in the breadth of the sector being measured, but it is also likely to be a result of using published BEA estimates of capital-stock growth in

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carriers from other industry participants. As a result, they have undoubtedly overstated productivity growth in the 1980s.

1981-87. The BEA capital-stock data are based in large part on sales of equipment, not telco purchases. Our capital-stock series are built up from actual capital expenditures by carriers. Between 1980 and 1987, we show a growth in industry capital of 12.5 percent, but the APC estimate for the same period is 38.0 percent.

Finally, we display recent estimates of TFP growth for Bell Canada, British Telecom, and AT&T. These estimates range from 2.5 percent for AT&T (1984-88) to 5.9 percent for Bell Canada (1985-88). The latter is above our estimate for the "Bell System" in 1985-88 while the former is substantially below our Bell System estimate. The AT&T estimate is only for AT&T's interstate services, not for the entire pre-1984 system.

More extensive estimates of Bell Canada's TFP growth for 1960-85 show a most striking pattern, given our results for the U.S.[37] There is no upward trend in Bell Canada's TFP in the 1970s, but a sharp upward trend in the 1980s after the 1982 recession. For the 1961-86 period for which data are available, a simple regression of Bell Canada's TFP (BELLCTFP) on output growth, the post-71 time trend, and a 1980s time trend (TIME80)[38] provides the following estimates (t-statistics in parentheses):

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37. These estimates were kindly provided by Dale Orr of Bell Canada.

38. This time trend is equal to zero in 1961-79, 1 in 1980, 2 in 1981, and so forth.

$$\text{BELLCTFP} = -1.08 + \underset{(3.94)}{0.63}\ \text{DQ} - \underset{(0.45)}{0.05}\ \text{TIME72} + \underset{(2.09)}{0.61}\ \text{TIME80}$$

$$\bar{R}^2 = 0.398$$
$$\text{DW} = 2.047$$

Given that Bell Canada enjoyed the same fruits of the electronics revolution in the 1970s and 1980s, it is noteworthy that its productivity did not begin to accelerate until the 1980s while TFP in the U.S. telecommunications began to accelerate in the early 1970s. The only obvious difference between Canadian and U.S. telecommunications in this period was that the U.S. began to admit entrants in the early 1970s, but Canada did not start liberalizing until the 1980s. Thus, liberalization is an obvious candidate for helping to explain the pattern of productivity growth.

Conclusion

Any estimate of TFP growth in an industry with rapid technical change is bound to be imprecise at best. The measuring of output and the flow of capital services is subject to numerous potential sources of error. Nevertheless, we have provided the first attempt to measure TFP growth in the U.S. telecommunications sector that employs a consistent methodology for Bell companies, independent telephone

companies, and telegraph carriers. We find that productivity growth began to accelerate in 1971 when the Federal Communications Commission announced its policy of liberalized entry into interstate telecommunication services markets. The 1984 AT&T divestiture temporarily reduced Bell "System" productivity growth by 3 to 5 percentage points per year in 1984 and 1985, but otherwise there has been no interruption of the upward trend in productivity growth since 1971 once one adjusts for cyclical movements in output. This result is obtained despite the slower output growth in the regulated telecommunications sector due to a series of FCC decisions concerning terminal equipment, inside wiring and competitive entry. We conclude therefore that any sacrifice of scale or scope economies must be minor and more than offset by the efficiencies and technical progress stimulated by competition.

Robert W. Crandall

July 31, 1990

APPENDIX

The Total Factor Productivity Series: Data and Alternative Results

The calculation of total factor productivity is based upon the growth accounting approach of Denison and Kendrick rather than recent translog estimation techniques. A Tornquist index is calculated for the entire (regulated) telecommunications sector, employing consistent data for output and inputs.

Output

As in all industries, output of telecommunications is quite heterogeneous. There is no physical output series, such as "calls" or "minutes of use" that will suffice to measure the output to a modern telecommunications sector. Instead, revenues for all carriers, -- local exchange, interexchange, and telegraph -- are aggregated by broad service category: