LEC are assigned to some input cost category. By contrast, the USTA assumed rate-of-return model presupposes a **long term user cost** per unit of capital, and assigns a total cost of capital, AC_K, that is the product of the quantity of capital input, K, and the long term user cost, p_K^*, which is based on an ***assumed* rate of return**. USTA's assumed cost of capital in carried forward into its calculation of the X-Factor. USTA's long-term user cost assumes that the capital stock **is fully adjusted to a level that minimizes total cost in each period**. This assumption is based on the principles of full competition: that the markets for inputs and outputs are fully competitive. The USTA model also assumes that there are no costs incurred by the LECs in adjusting to new technologies and to deregulation of their markets. Clearly, these conditions are not met at present in the markets for telephone services provided by the LECs.

When these assumptions are not met, then as Table 8 shows, there will be a residual in the USTA model. This residual may be positive or negative. If positive, it will correspond to an excess return to capital compared with the assumed long run equilibrium user cost. In economic terms, the residual is an economic rent to the enterprise, such as that occurring in the case of monopoly.

Why should total revenues exactly equal the total costs assigned to the inputs? There are two reasons: in principle, the economic theory of production requires it, and in practice, the regulatory authorities mandate it. The residual in Table 8 is just as much a cost to the ratepayers as is the total compensation of labor and the materials expense.

In a competitive market, the type of excess returns, described above, will tend to be eliminated by the entry or exit of firms. A positive residual will attract new resources to the industry, while a negative residual will cause some of the resources to be withdrawn, and to be allocated by their owners to other industries where the return is higher. Because the USTA model does not account for this residual in capital input in its calculation of TFP – the only point where the cost of capital enters the PCI formula – there is no incentive under its approach to price cap regulation for the LECs to adjust the quantity of capital to the overall cost-minimizing level. In other words, whatever level of capital a LEC chooses to put in place **is guaranteed a normal rate of return, just as under rate of return regulation**. But under price cap regulation, the LEC gets an added bonus with the USTA TFP approach: if the residual is positive -- that is, if total revenues exceed the costs of labor and materials, plus a normal return on capital – the LEC is permitted to keep the money. Unlike the competitive market, there is no incentive for the LEC to expand its capital and other inputs and move toward a cost-minimizing technology. The anti-competitive uses to which these residual amounts (excess profits) may be put -- e.g., subsidizing the LEC's penetration of the long distance market and entry into the cable television market -- must also be considered in evaluating the USTA proposed calculation method.

If, however, the Performance-Based Model for computing TFP is applied in the LEC price cap formula, then the residual – whether positive or negative – tends to be eliminated as the LEC responds to the economic incentives in the price cap index (PCI). In such a case, the price cap incentives more closely approximate those of the competitive marketplace. The effect

on the PCI is the key to the LEC's incentive to adjust its costs. In the Performance-Based Model the cost of capital, like all other costs, enters the PCI through the measured X-Factor – the measure of TFP growth.

For both the Performance-Based Model and the USTA model, TFP is the ratio of aggregate output to aggregate input. Aggregate input is based on the sum of all purchased inputs, measured in constant performance physical units, or in real dollars of some base period adjusted to a constant performance basis. Quality change in an input then reflects changes in the performance of a unit of that input revealed as the change in its marginal product, when output, all other inputs, and the technology of production are held constant. The cost share weights in the calculation of TFP are computed as shown in Table 8.[15] Aggregate or total factor input is the sum of indices of individual inputs weighted by their respective shares in total factor cost.[16]

Table 9 below shows how revenues paid by customers are allocated in the Performance-Based Model and the USTA model. In the Performance-Based Model, there is no excess return -- no remainder -- because all revenues are allocated to some cost category. In the USTA model there will be a remainder that may (in principle) be positive or negative because revenues are not balanced by costs.

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15 This statement holds exactly for the Tornquist Index in the USTA model. It is approximate to a rather high degree of accuracy in the Fisher Ideal Index used in the Performance-Based Model.

16 The weighting scheme that results from applying the Fisher Ideal Index to aggregate the inputs is slightly different, but the description here applies with little adjustment.

Table 9. ALLOCATION OF TOTAL REVENUES (TR) TO INPUT CATEGORIES			
Performance-Based Rate of Return Model			
Variable Costs (VC)		Allocated Return to Capital	Remainder
Labor: E_H	Materials: E_M	Capital: E_K	Excess Return
Total Compensation	Other Input Expense	TR - VC	0
USTA Assumed Rate of Return Model			
Variable Costs (VC)		Allocated Return to Capital	Remainder
Labor: E_H	Materials: E_M	Capital: AC_K	Excess Return
Total Compensation	Other Input Expense	Assumed Cost: AC_K	TR - VC - AC_K

The actual total cost (TC) authorized to the LEC by the price cap regulation process is the total revenue (TR) that the LEC receives. This actual total cost is the basis for the cost shares used in the TFP calculation in the Performance-Based Model. The *assumed* total cost (TC_A) in the USTA model differs from the actual total cost, TC, by the amount of the remainder. To understand the incentive effects of these different methods for computing the X-Factor, let us consider two situations: first, where there is a positive residual compared to the long run equilibrium, and second, where there is a negative residual. Each situation is analyzed for both models.

Case I. Positive Residual

Table 10 shows the case where the residual is positive. The correct weight for capital under the Performance-Based Model is shown to be 0.20 in the upper panel of the table; all costs and revenues are assigned to the appropriate inputs, and there is no remainder from the total costs levied on ratepayers. The incorrect weight assigned by the USTA assumed rate of return model is shown in the lower panel of the table; part of the revenues are not assigned to any input, and there is a ten percent residual from total costs levied on ratepayers. Thus, the USTA model weights the capital input, and hence the growth in capital input, too low. This results in understating the total factor input, and in understating the growth in total factor input when capital growth is positive.[17] Correspondingly, TFP and the growth in TFP – the X-Factor – are overstated. Overstatement of the X-Factor leads to higher measured performance of the LEC. Use of the correct weight would lead to a lower measured performance: lower TFP and a lower X-Factor. ***Note, however, that actual profits received by the LEC under the USTA assumed rate of return model are higher than those credited in the cost measure that enters the Price Cap Index formula.*** **This characteristic of the USTA model allows the LEC to gain in two ways: higher actual profits under the prevailing price cap, and a smaller downward adjustment of the price cap at the end of the current period.**

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17 This occurs when other things remain unchanged, and the growth rates of the other inputs together are approximately the same as the growth rate of capital input.

Table 10. SAMPLE CALCULATION OF COST SHARE WEIGHTS FOR POSITIVE EXCESS PROFITS

Performance-Based Rate of Return Model

	Actual Capital Cost: $E_K = 200$			
$E_H = 450$	$E_M = 350$	$E_K = 200$	Actual Total Cost: TC = 1000	
Labor Wt.	Materials Wt.	Capital Wt.	Remainder	Sum of Wts.
$E_H / TC = .45$	$E_M / TC = .35$	$E_K / TC = .20$	0	= 1

USTA Assumed Rate of Return Model

Actual Capital Cost: $E_K = 200$

Assumed Capital Cost: $E_{KA} = 100$

$E_H = 450$	$E_M = 350$	$E_K = 200$	Actual Total Cost: TC = 1000 Assumed Total Cost: $TC_A = 900$	
Labor Wt.	Materials Wt.	Capital Wt.	Remainder	Sum of Wts.
$E_H / TC = .45$	$E_M / TC = .35$	$AC_K / TC = .10$	.10	= .90 (Total Cost Basis)
$E_H / TC_A = .50$	$E_M / TC_A = .40$	$E_K / TC_A = .10$	0	= 1 (Assumed Cost Basis)

Case 2. Negative Residual

Table 11 below shows the case where the residual is negative. The correct weight for capital in the Performance-Based Model is .059, as shown in the upper panel of the table; all costs and revenues are assigned to the appropriate inputs, and there is no residual from the total costs levied on ratepayers. The incorrect weight assigned by the USTA assumed rate of return model, based on an assumed rather than actual return to capital, is shown in the lower panel of the table. Part of the cost assigned to capital is not received by the LEC, and there is a negative 5.9 percent residual from the total costs levied on ratepayers. Thus, the USTA model weights the capital input, and hence the growth in capital input, too high. This results in overstating the total factor input, and in overstating the growth in total factor input when capital growth is positive.[18] Correspondingly, TFP and the growth in TFP – the X-Factor – are understated. Understatement of the X-Factor leads to lower measured performance of the LEC, and thus lower allowed profits under the price cap incentive now in prospect. Use of the correct weight would lead to a higher measured performance: higher TFP and a higher X-Factor. But the actual profits to the LEC would be less than the assumed rate of return. **Note that actual profits received by the LEC under the USTA assumed rate of return model are lower than those credited in the cost measure that enters the price cap index formula**. This characteristic of the USTA model would force the LEC to *lose* in two ways: lower actual profits under the prevailing price cap, and a larger downward adjustment of the price cap at the end of the current

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[18] This is also subject to the conditions in the preceding footnote.

period. Because the details of the capital input and long-term user cost in the USTA model are not publicly available, and not accessible to other parties, it is not possible to compare directly USTA's assumed cost of capital and the actual capital cost levied on the ratepayers.

Table 11. SAMPLE CALCULATION OF COST SHARE WEIGHTS FOR NEGATIVE RESIDUAL

Performance-Based Rate of Return Model

Actual Capital Cost: $E_K = 50$

$E_H = 450$	$E_M = 350$	$E_K = 50$	Actual Total Cost: TC = 850	
Labor Wt.	Materials Wt.	Capital Wt.	Remainder	Sum of Wts.
E_H / TC = .529	E_M / TC = .412	E_K / TC = .059	0	= 1

USTA Assumed Rate of Return Model

Actual Capital Cost: $E_K = 50$

Assumed Capital Cost: $E_{KA} = 100$

$E_H = 450$	$E_M = 350$	$E_{KA} = 100$	Actual Total Cost: TC = 850 Assumed Total Cost: $TC_A = 900$	
Labor Wt.	Materials Wt.	Capital Wt.	Remainder	Sum of Wts.
E_H / TC = .529	E_M / TC = .412	AC_K / TC = .118	-.059	= 1.059 (Total Cost Basis)
E_H / TC_A = .50	E_H / TC_A = .40	E_H / TC_A = .10	0	= 1 (Assumed Cost Basis)

From the analysis of these two cases, the LECs would be likely to advocate the USTA assumed rate of return model if they expect to earn a higher actual rate of return than that assumed in USTA's calculation of the X-Factor. Similarly, it is clear that an X-Factor computed from the actual performance-based rate of return is fairer to customers and to the interexchange carriers (IXCs) simply because it reflects all the costs levied on them.

c. The USTA model does not distinguish between the costs of debt and equity capital.

Recent work in the theory of capital asserts the importance both theoretically and quantitatively of the distinction between debt and equity capital.[19] Much of the earlier work in productivity analysis, however, omitted this distinction. The common practice in the past was to treat the entire return to capital as if it were subject to the federal corporate income tax. This practice resulted in an upward bias in the economic user cost of capital, because it overstated the tax liability, and thus overstated the amount that must be earned to meet the enterprise's tax bill and provide a normal competitive return on investment.

This effect is illustrated in Table 12 below for several major airlines for the 1972-1986 period. Table 12 shows that for highly leveraged enterprises the overstatement of the user cost is substantial when the debt/equity distinction is ignored and all returns to capital are incorrectly assumed to be taxable.

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[19] Jorgenson and Yun (1991); Jorgenson (1993); Norsworthy and Tsai (1996, ch. 3, forthcoming) (chapter 3 of the last-named text is attached hereto as Attachment 2).

Table 12

USER COST OF CAPITAL, 1972 - 1986
SELECTED MAJOR AIRLINES

Airline	Consistent with Financial Theory	Omits Debt/Equity Distinction
American	6.96%	11.66%
Northwest	5.08%	7.79%
United	6.11%	10.52%

Source: Norsworthy and Tsai (1996, forthcoming) ch. 3.[20]

In recent years, it has been recognized that the proportion of debt and equity in the firm's capital structure must be recognized. In the USTA model, the cost of capital was determined on the basis of the yields on Moody's Public Utility Bonds. These bond yield rates were applied to the capital of the LECs on the assumption that their capital was all-equity and that no part of the return to capital was represented by interest on debt, which is tax-deductible. The USTA assumptions are simply incorrect. They result in an upward bias in the cost of capital in the USTA model.

In 1991 and 1992, the ratio of debt to the total of debt and equity for the RBOCs averaged about .52 according to ARMIS. With a corporate tax rate of about 40%, ignoring the

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20 A copy of chapter 3 of the forthcoming text by Norsworthy and Tsai, to be published in 1996, is attached hereto as Attachment 2 to Appendix A.

tax-deductible status of interest paid on debt would overstate the user cost of capital by about 30% of its correct value. The implied rate of return on investment in the USTA model should be reduced by about 23% in order to reflect the proportions of debt and equity in the capital structure. This error results in an understatement in the USTA model's calculation of TFP and the X-Factor.

The type of effect from ignoring the debt-equity distinction in computing the user cost (or rental price) of capital is illustrated in the figures shown in Table 12. This table is based on the balance sheets of three major airlines. Details are reported in chapter 3 of Norsworthy and Tsai (1996) which is attached (Attachment 2).

d. Depreciation in the USTA model departs from that authorized by the FCC.

The depreciation of capital in the USTA model is different from that authorized by the FCC. **Depreciation** and the **rate of return** interact; lower depreciation, when other things (revenues, investment, etc.) remain the same means that the **measured capital stock** will be higher. The rate of return will also be somewhat higher, because reducing depreciation has the effect of moving a flow of money from a **tax-deductible expense** – depreciation – to **taxable profits**. There will thus be a preference on the part of a profit-making business to assign greater costs to depreciation, and thereby reduce its tax liability. In normal business practice, **allowable depreciation** under the U.S. tax code has no direct counterpart in **economic depreciation**. But for the LECs, there is an additional incentive to choose higher rates of depreciation in the calculation of TFP, because higher depreciation results in a higher (assumed) **user cost of capital**. This higher user cost will tend to reduce the profits, and hence the apparent return on invested

capital in the TFP calculation, when other conditions are held constant.

"Economic" depreciation properly includes two components: **loss of function** and **obsolescence**. Loss of function is generally appraised in terms of the **service life of an asset**. If an asset is expected to last, say, for ten years in normal use, then straight-line depreciation would reduce the value of that asset by ten percent of its original cost each year for ten years. Obsolescence occurs when the economic usefulness of the asset is reduced by any of several factors, including **shifting demand** (the familiar plight of the buggy-whip manufacturers), **technological advances** (new, more cost-effective switching equipment), or a decline in the replacement cost of the asset (which may be caused by technological advances, competition in the input markets or other conditions). Obsolescence can be detected empirically for assets that have active second-hand markets.[21] This was the methodology used in the Hulten and Wykoff (1981) study.[22] The data considered in their study involved a period that ended in 1972 -- well before divestiture in 1984. Furthermore, the Hulton-Wykoff study did not use data based on transactions involving telecommunications plant and equipment, because such data were not available to them.[23] Rather, a composite of other industrial capital was used. Consequently, there is no post-divestiture pricing of telecommunications plant and equipment -- indeed, no data on

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21 Norsworthy and Jang, Pacific Telecommunications Conference, 1992.

22 The depreciation rates from Jorgenson, as cited in the USTA model of TFP, come from the Hulten-Wykoff study.

23 This comment should not be interpreted as a criticism of the Hulten-Wykoff study, which was candid about this shortcoming. Rather, it is a criticism of the USTA study, which did not cite Hulten and Wykoff directly, but instead cited a study by Jorgenson which used the Hulten-Wykoff result. USTA's approach may easily give the misleading impression that the depreciation rates it uses are related to telecommunications, which it is not.

telecommunications facilities at all -- that underlies the depreciation rates employed in the USTA measures of TFP. There is no empirical or theoretical reason to believe that USTA's depreciation rates would apply to telecommunications assets in the post-divestiture period. The fact that the depreciation rates authorized by the FCC are lower than those used in the USTA model -- a composite of 7.1 percent vs. 8.1 percent -- would suggest that the USTA depreciation rates are too high.[24]

Thus, while there is a *logical* basis to conclude that economic and accounting depreciation are not congruent, that does not constitute a *positive* case for using depreciation rates from other industries in the 1970s and earlier for application to modern telecommunication equipment. Indeed, the depreciation charges at the LECs have accelerated in recent years. Concerning the depreciation rates allowed by the FCC, the recent decision to allow more rapid amortization of depreciation reserves may be thought of as "catching up" on theretofore deferred obsolescence charges. The appropriate empirical approach to this problem would be to collect data on recent transactions involving second-hand sales of telecommunication equipment by the LECs, and to carry out a study of depreciation using the Hulten-Wykoff methodology.

e. The USTA model does not adjust for changes in the performance of capital.

The changes in telecommunications technology in the last ten years are perhaps as great as in any other industry except computers. The available data suggest that there have been important quality improvements during recent years in two key categories of

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24 These composite rates are derived from worksheets supplied by Christensen Associates to the California Public Utility Commission in recent rate hearings.

telecommunications equipment: switching and transmission. Table 13 reports the diffusion of switch types among Bell Operating Companies (BOCs).

Table 13. Access Lines Served, by Technology, for all Bell Operating Companies

	Percent Served, By Switch Type				
Year	Total Lines (Millions)	Electromechanical	Digital SPC	SS#7	Equal Access
1980	80,234	56.1	0	0	0
1981	82,709	49.3	.1	0	0
1982	83,716	44.1	.2	0	0
1983	85,924	38.1	.6	0	0
1984	88,546	34.1	2.3	0	4.0
1985	91,442	28.1	7.7	0	51.1
1986	93,863	21.4	15.3	0	74.5
1987	96,654	15.0	23.4	1.1	84.2
1988	99,524	9.0	31.0	10.4	92.0
1989	102,648	5.8	36.9	21.0	94.7
1990*	105,844	3.2	43.0	34.7	97.0
1991*	109,228	1.9	47.3	47.8	97.7
1992*	112,476	1.2	51.2	59.0	98.3
1993*	115,700	.9	54.2	68.0	98.7
1994*	118,961	.7	57.2	73.1	99.0

Notes:

* Projected, in CC Docket 89-624

Digital SPC: Switches that are computers, based on stored program control (SPC.). SPC switches can be either analog (whose use peaked in 1985) or digital. Non SPC switches are electromechanical.

SS#7: A recent version of SPC switches (Signaling System #7) that allows for enhanced network services.

Equal Access: Switches designed to access non-AT&T interexchange carriers without dialing a 10 digit access code.

SOURCE: Annual BOC reports filed with FCC.

Digital electronic switches were introduced into the U.S. market in 1977; digital switches provide large increases in capacity, speed, and signal clarity. As Table 13 shows, in 1980 most lines were still served by older electromechanical (crossbar and step-by-step) technologies. Electronic switches spread rapidly during the 1980's. Early electronic switches were analog; their use peaked in 1985, as digital switches began to account for a rapidly growing share of the total. Later versions of digital switches provide continuing improvements along these lines as the switches, which are dedicated computers, benefit from the same technological advances that have led to dramatic advances in computer quality. The BOCs have moved quickly to deploy SS#7 digital signaling systems that will equip their access lines with enhanced network services. It was projected that 87 million BOC access lines (73% of the total) would be equipped with SS#7 access by 1994, up from 1 million in 1987.

Table 14 shows the effect of quality adjustments on reported telephone price indices (TPIs). Most cost studies measure switch prices by using the relevant telephone plant indices developed at AT&T and at the LECs. Prior to divestiture, AT&T's TPI series also formed the basis for the price series on telephone switches reported in the federal government's Producer Price Index. The TPI is a "matched model" index; that is, it includes price changes of existing models, but makes no attempt to calculate the fall in price or improvement in quality brought about when a new model is introduced. New York Telephone's TPI measures changes in the price of the boxes (switches) that New York Telephone buys; but it does not capture the increased performance in terms of speed or capacity associated with an improved switch. If

switch capacity and speed are improving, so that the LEC needs fewer switches, the TPI may increase as switch prices increase, but capital costs per line may be declining as a given switch handles more traffic.

Table 14. The Effect of Quality Adjustment on Capital Equipment Prices

Year	New York Telephone's TPI	AT&T TPI	Gordon Quality Adjusted Index
1960	58.7	71.0	104.0
1961	59.3	70.9	101.7
1962	60.2	71.0	108.2
1963	61.5	72.0	95.1
1964	63.6	73.5	95.4
1965	65.6	73.8	78.5
1966	67.8	75.4	80.2
1967	71.2	78.2	76.9
1968	75.7	81.7	77.6
1969	81.4	86.1	79.2
1970	87.1	90.0	84.8
1971	95.6	98.9	94.0
1972	100.0	100.0	100.0
1973	106.3	104.0	99.7
1974	119.2	113.9	109.4
1975	132.6	124.7	110.3
1976	142.8	132.3	106.9
1977	151.0	137.4	105.3
1978	157.3	137.9	104.9
1979	168.5	141.5	95.6
1980	181.6	147.8	82.9
1981	197.7	160.4	85.6
1982	213.5	176.0	88.9
1983	229.4	185.4	76.0
1984	240.4	188.6	65.0
1985	233.3	191.5	57.2

SOURCE: Gordon Quality Adjusted Index: Gordon (1991); NYTEL TPI: R.E. Bischoff, "New York Telephone Plant Indexes, Mimeo, December 1988, New York Telephone Company; AT&T TPI: "Bell System Telephone Plant Indexes," prepared by Economic Analysis Section, Planning and Financial Management Department, AT&T, December 1983. .

Norsworthy and Jang (1992, chapters 6 and 7) demonstrated the importance of quality-change adjustments in productivity measurement, particularly in the information-technology industries using a hedonic approach in the cost function. Adjusted for quality changes, computer prices fell dramatically at an average annual rate of 19.8 percent per year between 1959 and 1982 (from an index value of 2422.7 to 20.4). In contrast, the government's price index for semiconductors, which is not adjustment for quality change, increased from 129.5 in 1959 to 142.6 in 1982. The price decline for computers is mainly due to rapid technological change which has a significant effect on its productivity growth. Based on the quality-adjusted price index, the average annual rate of productivity growth for computers is about 26.31% for the period 1959-81.[25]

Robert Gordon and Kenneth Flamm each have calculated a quality-adjusted price series for central office circuit and radio equipment using Bellcore data. Gordon's series is reproduced in Table 14. His series is a three-year moving average of the incremental capital cost of new output (the change in the net book value of central office circuit and radio equipment, and toll and exchange lines, divided by the change in circuit miles). Comparing the New York Telephone TPI for all capital and the AT&T TPI series reproduced by Gordon, there are sharp divergences shown in the series. Quality adjusted prices fell sharply between 1962 and 1965, then tracked the trend of the TPI until 1974; but after 1974, the AT&T TPI grew by 53.6% (less than the rate of inflation measured by the overall producer price index, which doubled) while the quality adjusted measure of capital prices per new line fell by 48%.

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25 See Jang and Norsworthy (1988); Norsworthy and Jang (1992).

It should be noted, however, that New York Telephone's price index (TPI) is for electronic switches, and its price series *does not* adjust for quality improvement.

Another source of information bears on this issue. Flamm reported the results of hedonic regressions of switch prices. He obtained data on transactions prices for small and medium size switches, whose purchases were financed by the Rural Electrification Administration (REA) of the U.S. Department of Agriculture. The REA data included information on price, date of purchase, and switch characteristics (speed, capacity, other features). Using those data, he estimated mean prices in each year, for a switch of fixed characteristics.

Holding quality characteristics constant, medium switch prices fell by 24% (from $458,000 to $347,000) between 1982 and 1985.[26] Gordon's Bellcore index, which adjusts for changes in quality, fell by 36% in 1982-85. But New York Telephone's price index (the TPI) for electronic switches, which does not adjust for quality improvements, fell by only 7% during that period. Even without quality adjustment, switch prices fell, and fell quite sharply after 1985, as competition among switch makers drove prices down. Finally, the Organization for Economic Cooperation and Development (OECD) estimates that the cost

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26 In a hedonic regression, Flamm regressed switch prices (the dependent variable) on several measures of switch characteristics, and on dummy intercept terms for each year. That approach allowed him to estimate the value of improvements in the characteristics (with the estimated coefficients), and also provides estimates of year to year price changes for a switch of given characteristics. That approach was needed because switch quality (the characteristics terms) have been improving through time.

per line for new digital switches fell by 49% between 1980 and 1990.[27]

Other technological advances have occurred in transmission equipment. These are associated with the development of fiber optic systems, which potentially possess enormous capacities. Fiber systems have become feasible in recent years, as fiber prices fell by 90% between 1980 and 1990, and as improvements in fiber quality reduced requirements for some associated electronics. In turn, the LECs have greatly expanded their fiber networks, from 500,000 fiber miles in 1985 to 2.35 million fiber miles in 1989, most of it dedicated to high volume interoffice transport.[28] With the development of improvements in repeater and terminal electronic equipment, the capacity associated with any given fiber system doubled every 18 to 24 months during the 1980's.[29] As a result, LEC fiber transmission capacities have expanded more rapidly than the increases in fiber mileage alone would suggest.

As this overview of the literature clearly demonstrates, there is substantial evidence that the effective prices of switching equipment, based on standard performance, have declined more rapidly than is indicated by the prices used in the Christensen Study. We are likely to see continued technological changes in switching and equipment. For calculating TFP growth in the LEC price cap system, it is necessary to measure the prices and quantities of capital inputs accurately in order to assure that their impact on future productivity arising

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27 OECD (1991).

28 Kraushaar (1990).

29 Walker (1990).

from technological changes in capital inputs is considered. It is therefore important to adjust the capital stock for changes in performance. This was not done in the USTA model.

There are two main approaches to quality adjustment based on statistical techniques, both of which are categorized in the literature as hedonic methods. Berndt, Griliches and Rappaport (1995) have applied hedonic methods to determine quality change in personal computers based on the array of opportunities to purchase PCs with various performance characteristics. Norsworthy and Jang (1993) applied a different type of hedonic adjustment to semiconductors used in producing telecommunications equipment and computers, which analysis relied on estimating the hedonic weights in the context of a cost function. Norsworthy, et al. (1993) applied a quite similar technique to measure a hedonic price adjustment for capital input at eleven large LECs for the period 1980 to 1990. The last study shows a fairly rapid decline in the effective price per unit of capital input for the LECs. When the rate of price decline from 1981-1990 is extrapolated to 1991-94, the series shows an annual rate of decline of 3.27 percent per year for the period 1985 to 1994, as set forth in Table 15 below. It is important to note that this study was applied to the book value of the net capital stock of the LECs, not to new equipment, as in the Gordon and Flamm studies. The quality adjustment from the study has been applied to the capital stock in the Performanced-Based Model. Berndt and Norsworthy are currently commencing a collaboration to update this last study and to investigate the sensitivities of both the USTA and Performance-Based Models to quality changes in capital inputs. These results are not yet available.

Table 15. Adjustment of Capital Input for Quality Change
ALL RBOCs, 1984-1994, Indexed 1985 = 100

	Quality Adjustment	Capital Input Price Unadj.	Capital Input Quantity Unadj.	Capital Input Price Adj.	Capital Input Quantity Adj.
1984	1.013	0.960	0.953	0.972	0.941
1985	1.000	1.000	1.000	1.000	1.000
1986	0.974	1.021	1.048	0.994	1.076
1987	0.934	1.035	1.097	0.967	1.175
1988	0.892	1.059	1.164	0.945	1.305
1989	0.858	1.099	1.211	0.943	1.411
1990	0.834	1.143	1.254	0.951	1.507
1991	0.806	1.169	1.300	0.943	1.613
1992	0.782	1.194	1.359	0.933	1.739
1993	0.758	1.206	1.408	0.914	1.858
1994	0.745	1.234	1.427	0.920	1.914
Average Rate of Growth	**-3.27%**	**2.34%**	**3.95%**	**-0.93%**	**7.22%**

5. The USTA Model Erroneously Uses Revenue Weights to Aggregate Output.

The USTA model uses **revenue weights** to aggregate outputs into an index of total output. The economic theory of production clearly specifies that the correct weights to use for this purpose are **marginal cost weights**.[30] Only under circumstances of competition in the markets for outputs is there reason to expect that the marginal cost for each output will be equal to its price. Patently, this condition is not met presently in the markets for local telephone service or in the markets for access to the local loops.

As a matter of economic principle, there is little disagreement that marginal cost rather than revenue weights should be used to aggregate output. The difficulty arises in trying to apply this principle. Estimates of marginal costs based on **an allocations of accounting data** are generally viewed as unsatisfactory because arbitrary elements are likely to be reflected in the allocators. Statistical methods to estimate marginal costs may not be **robust**: the resulting marginal cost estimates may vary widely in response to small changes in the specification of the statistical or econometric model. While acknowledging this problem, it is worthwhile to see what gains in accuracy are likely to result **from econometric measurement of marginal cost**.

The results reported below in Table 16 are from a time series model of the U.S. Postal Service estimated by Norsworthy and Jang (1992). The marginal cost estimates from that model are robust because revenue equations were added to the conventional

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[30] Fisher and Shell (1972); Diewart (1993) ch. 13, Diewart and Nakamura (1993).

specification of the variable cost function.[31] Table 16 shows for the U.S. Postal Service the difference between revenue-based and marginal cost-based aggregation of multiple outputs to a single output.

The three weighting methods for aggregation in general use are:

(1) Marginal cost weighting

(2) Revenue weighting

(3) Average cost weighting

In all three methods, the preferred procedure is to use annual, rather than fixed, weights. Marginal cost weighting is consistent with the economic theory of production. Marginal cost and revenue weighting are equivalent under conditions of perfect competition (i.e., when price equals marginal cost). Marginal and average cost weighting are equivalent only under conditions of constant returns to scale and fully adjusted producer equilibrium (i.e., when marginal cost equals average cost equals price).

Dr. Christensen previously advocated using average costs for different mail classes obtained by regressing total cost on outputs. That procedure results in estimates of average cost when the constant term in the regression is restricted to zero. I attempted to compare this last method in the U.S. Postal Service study also, but consistently I obtained negative weights for third-class mail, or zero weights when the coefficient for third-class mail was restricted to being no less than zero. Because the resulting weights made no economic

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31 Norsworthy and Jang (1992) ch. 12.

sense, I did not compute a corresponding aggregate index in the Postal Service study.

The data on which the marginal cost model was based were derived from Christensen Associates' report in 1985 to the U.S. Postal Service on total factor productivity. The model for estimating marginal cost is reported in Norsworthy and Jang (1992), Chapter 12.

Table 16 shows the results of comparing the two methods of aggregation. Viewed as an estimate of marginal cost weights for output, the revenue weights result in growth rates that depart from the marginal cost-based rates by an average of one-third of the annual growth rate per year. In the context of price cap regulation of the LECs, this variability is too great for a price cap horizon of three or four years.

An implication of marginal cost measurement in the Norsworthy-Jang framework is that markup over marginal cost can be determined for each class of service. In the Postal Service study, these markups confirmed the general perception that first-class mail, where the Postal Service is more protected from competition, is priced well above marginal cost, while third class mail is priced at or below marginal cost. While stable estimates of marginal costs for output aggregation in telecommunications may be difficult to achieve, the effort is warranted because of the central role that telecommunications plays in the modern U.S. economy. The pooling of time series and cross sectional data for the LECs, with the use of revenue equations, may stabilize the results.