Appendix A

Sources of Potential Errors in the 1997 Staff TFP Study

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A review of the 1997 Staff TFP Study, upon which the Commission relied in its *1997 Price Cap Review Order*,[1] has identified a number of potential errors that appear to affect significantly the results of the study. Below we discuss a possible conceptual error and a method of correcting the problem. We then discuss three sources of potential bias that are attributable to the study's sources of data and how these potential biases can be corrected. Finally, we discuss a number of other sources of possible bias. These possible biases either are not easily quantified, or do not have a significant impact on the level of the X-factor.

I. Competitively Determined Historical Cost of Capital

The 1997 Staff TFP Study used actual imputed cost of capital when measuring the productivity of regulated companies. Several parties allege that this creates a problem, because of the use of the residual value approach for determining the cost of the capital input.[2] With this approach, the Commission in the *1997 Price Cap Review Order* first directly determined the price and quantity of every input except capital, *i.e.*, labor and materials. That is, it directly calculated the realized return to every non-capital input. Next, based on an estimate of the capital stock, the assumption that all revenue is distributed to the inputs,[3] and given the returns to labor and materials based on historical data, a cost of capital is imputed.

[1] *Price Cap Performance Review for Local Exchange Carriers*, Fourth Report and Order in CC Docket No. 94-1 and Second Report and Order in CC Docket No. 96-262, 12 FCC Rcd 16642 (1997) ("*1997 Price Cap Review Order*").

[2] *See* Reply Comments of Ad Hoc, CC Docket No. 94-1 at 18 (Nov. 9, 1998) (arguing that the Commission's model, measuring the input cost of capital as a firm's overall return on investment, does not accurately calculate the capital costs in a market that is not competitive); Reply Comments of AT&T, CC Docket No. 94-1 at 19 (Nov. 9, 1998) (arguing that the Commission's miscalculated increase in incumbent LEC input prices is due mainly to the huge surge in incumbent LEC operating earnings in 1996 and 1997); Reply Comments of MCI, CC Docket No. 94-1 at 27-28 (Nov. 9, 1998) (arguing that, under the Commission's X-factor calculation, higher earnings on the part of LECs would actually suggest lower productivity).

[3] The validity of conventional TFP models depends on several assumptions. Generally, the analysis assumes constant returns to scale and that the market is in competitive long-run equilibrium. *See, e.g.*, Ernst R. Berndt & Melvyn A. Fuss, *Productivity Measurement with Adjustments for Variations in Capacity Utilization and Other Forms of Temporary Equilibrium*, 33 Journal of Econometrics 7 (1986), and Dale W. Jorgenson & Zvi Griliches, *The Explanation of Productivity Change*, 34 Rev. Econ. Stud. 249 (1967). If these assumptions are not met, it may not be appropriate to apply the results of the analysis to set an X-factor. Note that constant returns to scale exist if doubling all inputs causes output to double, tripling all inputs causes output to triple, and so forth. *See* Richard A. Bilas, *Microeconomic Theory* 120 (1971). In some cases, modifications in the calculations can be made to take account of the departure from the assumptions of the model.

Conceptually, the difference (residual) between revenue and the required returns to all non-capital inputs (which is just the nominal amount used to impute a cost of capital) consists of two parts. The first part is the required return to capital. The second part is the excess profit earned by the firm. Instead of attempting to separate this difference into two parts, the Commission in the *1997 Price Cap Review Order* assumed that all of this residual was the required return to capital, *i.e.*, that no excess profit was earned. This is a reasonable assumption for a competitive market, and even for non-competitive markets, as long as the goal of the study is simply to measure the productivity gains revealed by market forces.[4] In a regulatory setting, however, the productivity gains are "revealed" by the application of the X-factor, not by market forces.

By attributing all of the residual to the capital inputs, the residual value method tends automatically to define whatever profits or losses the LECs realized during the historical period as increases or decreases in the cost of capital inputs. Critics contend that if, for example, the Commission chose too low an X-factor during the historical period being considered, causing the LECs' profits to increase, the residual value method would indicate that the historical cost of LEC capital inputs rose more rapidly during this period than it actually did. The Commission then would predict an equally large growth in LEC capital cost in the future, and thus calculate an X-factor that was still too low.[5] Consequently, critics contend that LECs' profits would continue to increase despite no increase in LEC productivity. On the other hand, suppose that the Commission chose too high an X-factor during the historical period, causing LECs' profits to decrease. Critics contend that the residual value method would indicate that the historical cost of LEC capital inputs fell more rapidly during this period than it actually did. The Commission then would predict an equally large price reduction for capital in the future, and thus calculate an X-factor that was still too high. Consequently, LECs' profits would continue to decrease despite no decrease in LEC productivity. In either scenario, critics claim, the LECs' productivity remains constant; only their rate of return is affected by the incorrect X-factor. Thus, they assert that the residual value method produces an X-factor that is biased in the same direction as whatever bias existed in the historical period.

Accordingly, the critics' theory posits that, to avoid this problem, any TFP study of a regulated industry should augment or reduce the actual amounts of capital compensation in such a way as to duplicate the forces of a competitive market. USTA proposed an index similar to the one we are using.[6] What USTA did not do is reduce the revenue as capital compensation went down. To capture the gains in productivity that would have been revealed in a competitive marketplace, total capital compensation must vary with the competitive capital compensation rate.

In order to correct the alleged miscalculation of the LECs' cost of capital in the 1997 Staff TFP study, it is necessary to replace the TFP study's cost of capital with a competitive cost for the inputs

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[4] Dale W. Jorgenson & Zvi Griliches, *The Explanation of Productivity Change*, 34 Rev. Econ. Stud. 249-283 (1967).

[5] One component of the X-factor calculation is the difference between the US Economy's average input costs and the historical input costs of LECs. Thus, an artificially high LEC capital input cost would lead to an artificially low X-factor.

[6] Letter from Mary McDermott, Vice President – Legal & Regulatory Affairs, USTA, to William F. Caton, Acting Secretary, FCC, Jan. 20, 1995, Attachment at 11.

during the historical years. Next, it is necessary to adopt a surrogate to emulate a competitive cost of capital for LECs because LECs have never operated in a competitive market. This study employs an independent price series to compute the annual change in the cost of capital for a competitive market.[7] Specifically, Moody's Baa corporate bond rate reported in the *1999 Economic Report of the President* (Table B-73) is used to calculate the adjustment.[8] Combining the base year[9] imputed cost of capital from the 1997 staff TFP study with the change in the competitive cost of capital gives an independent competitive cost of capital for LECs in each year of the historical period. This competitive cost of LECs' capital input is used in conjunction with an adjusted cost of labor (see below) and materials inputs from the 1997 staff TFP study, as well as the percent change in the U.S. nonfarm business sector input price growth, to compute the corrected input price differential portion of the historical X-factor.[10]

Recalculating the LECs' historical cost of capital changes the level of the LECs' revenues, taxes, and operating expenses for the historical years. If we take the difference between our estimate of the competitive cost of LECs' capital inputs and the imputed cost from the 1997 staff TFP study, we obtain an estimate of the excess profits realized by LECs for each year of the historical period.[11] Reducing the LECs' total revenue by this amount results in a revenue stream that emulates what LECs would have realized in a competitive market. A reduction in revenue implies a reduction in taxes,[12] which in turn reduces operating expenses.[13]

Reducing LEC revenues to what would have been realized in a competitive market also changes the LECs' TFP portion of the X-factor. The new revenue level changes the LECs' input growth rate by

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[7] Following standard financial economics convention, the absolute magnitude of the change in the independent price series is used in deference to the relative change.

[8] Any index for a competitively determined cost of capital should be acceptable because changes in the cost of capital in competitive markets is similar across markets. The use of a different series would yield comparable results given the competitive nature of financial markets. For example, the correlation over the period 1985-1998 between Moody's Aaa corporate bond rate and the Baa rate used is 0.99. Analogously, the correlation between the 10-year U.S. Treasury securities rate and the 30-year U.S. Treasury securities rate and Moody's Baa rate over the same period is 0.99 and 0.98, respectively. In terms of changes in the absolute level of the series, the correlation between Moody's Baa corporate bond rate and Moody's Aaa corporate bond rate, the 10-year U.S. Treasury securities rate, and the 30-year U.S. Treasury securities rate over the period 1985-1998 is 0.99, 0.98, and 0.97, respectively.

[9] The base year is 1991. This is the first full year of LEC price cap. We are assuming that LEC returns on capital for this year were at a competitive level. That is, it is assumed that LECs earned a normal return in that year.

[10] This results of this calculation is found in column H of Table B-12 in Appendix B. Note that in the 1997 staff TFP study, we estimated the U.S. nonfarm business input price for 1995 because the data were unavailable at that time. In this Notice, because the data are now available, we use the actual 1995 value.

[11] The LECs' excess profits are due to their output prices falling slower than their cost of capital during the historical years. This situation would not have occurred in a competitive market.

[12] Following standard Commission procedures we assume that taxes are 39 percent (34 percent federal and 5 percent state).

[13] Taxes are one component of operating expenses.

altering the relative share of revenue accounted for by each input:[14] labor, materials, and capital.[15] In other words, the LECs' input growth rate changes in response to the changes in the relative weight of each input factor.[16] Combining the output growth rate from the 1997 staff TFP study with the revised LECs' input growth rate yields the corrected TFP growth rate for the LECs.[17]

II. Other Modifications to the 1997 Staff TFP Study

In addition to updating the data for the period 1996-1998, the study concludes that a number of adjustments to the study reasonably could be performed to improve the 1997 Staff TFP Study's accuracy. First, we could substitute the recently revised BLS series on multifactor productivity for the series previously employed.[18] In addition, our recalculation of the X-factor could adjust for potential biases in the local service output index and the price of labor. These adjustments are easily quantified and are likely to have a significant impact on the level of the recalculated X-factor.

The potential bias in the LECs' local output index would affect the LEC's TFP. The local service output index from the 1997 staff TFP study was based on the number of local calls. Because the length of calls can vary significantly, however, basing the LECs' local output index on the number of dial equipment minutes (DEMs) more accurately measures the use of the LECs' local equipment. For much of the period beginning in 1985, the average length of a local call measured by the number of local DEMs divided by the number of local calls was approximately constant. Beginning in 1992, however, there is a pronounced upward trend in local call length. This trend is attributable in large part to the increase in the use of the Internet by local subscribers. This increase has important implications for measuring local output and, in turn, LECs' TFP. Using the number of local calls as the output measure, output increased between 1992 and 1997 at a 3.5 percent annual rate. On the other hand, using the number of DEMs as the local output measure, output increased at a 6.5 percent annual rate.

[14] Note that, in using shares to aggregate inputs, the 1997 staff TFP study introduced another source of bias. Namely, the observed shares were not cost minimizing shares (*i.e.*, the factors are not paid the value of their marginal products as assumed in the TFP approach). The correction makes an adjustment for this bias.

[15] Our recalculation does not change the labor and capital input quantities indexes. The materials input index, however, (computed as the total operating expenses minus labor compensation, depreciation, and amortization), changes when the operating expenses are reduced.

[16] The change in relative weights means that the weights used in computing the LECs' input price growth must be recomputed which, in turn, implies a recomputation of LECs' excess profits, etc. This an iterative process. The new LEC input growth rate is found in column C of Table B-12 in Appendix B.

[17] The difference between the LECs' TFP growth rate and the growth rate of the TFP for the U.S. nonfarm business section is in column E of Table B-12 in Appendix B. The 1997 staff TFP study approximated the U.S. nonfarm business sector TFP value for 1995 because the actual data were not available at that time. Since these data are now available, we update these data using the Bureau of Labor Statistics revision of the entire multifactor productivity series dating back to 1985.

[18] The nature of this update in the BLS multifactor productivity series is discussed in John Duke & Lisa Usher, *BLS Completes Major Expansion of Industry Productivity Series*, 121 Monthly Lab. Rev., 35-51 (1998). The specific series used was obtained from the Bureau of Labor Statistics web site (www.bls.gov) for multifactor productivity. The annual series is from Table 2: Private Nonfarm business: Productivity and related indexes, 1948-97.

Because the data are not yet available, it is necessary to forecast two 1998 values used in computing the X-factor - the number of local dial equipment minutes and the multifactor productivity. Local dial equipment minutes for 1998 are forecast using an extrapolation of the average rate of growth in dial equipment minutes beginning in 1992.[19] The multifactor productivity value for 1998 was forecast using a structural model relating the natural logarithm of the multifactor productivity to the natural logarithm of the output of all persons employed.[20] This second series is reported by the Bureau of Labor Statistics, and its value for 1998 is available. The parameter estimates of the structural model in conjunction with the 1998 value for output per hour of all persons employed gives the forecast of 1998 multifactor productivity.

Another adjustment we could make concerns the price of labor. This problem has further implications because labor's share of total factor payments will be inflated relative to the other factors of production. Between 1985 and 1998, the price of labor, defined as the average compensation per employee,[21] increased in real terms at a 3.6 percent annual rate. In terms of total compensation, the amount paid for labor was approximately the same in 1985 as it was in 1998 even though the number of workers in the aggregate had been reduced by over 30 percent. The reason for this, at least in part, is that, coincident with the adoption of price cap plans, labor force reductions were accomplished by offering employees monetary incentives to leave the company (*i.e.*, buyouts). There is some variability in the applicable accounting rules,[22] but these payments were generally accrued as one-time charges against current earnings.[23] This will tend to inflate costs in the early years after the implementation of price caps and, in turn, bias the measure of TFP_{LEC} growth downward for these periods.[24]

The resulting recalculation of the X-factor, in which we use a competitively determined cost of capital, update the multifactor productivity series, substitute a better measure than the number of calls for

[19] Data beginning in 1985 could have been used in fitting the functional relationship used to produce the forecast. Because there was an identifiable structural change in the data series beginning in 1992, taking account of this structural change would yield a model equivalent to that based on data beginning in 1992. The coefficient of determination for the estimated model was 0.97.

[20] Regression diagnostics indicated that 1991 was an outlier. A dummy variable was inserted to capture the effects of this. The coefficient of determination on the fitted model was 0.88.

[21] The average compensation per employee is equal to total labor compensation divided by the number of employees.

[22] *See*, e.g., Financial Accounting Standards Board Rule (FASB) Number 106.

[23] Donald J. Kridel *et al.*, *The Effects of Incentive Regulation in the Telecommunications Industry: A Survey*, 9 J. Reg. Econ. 269-306 (1996).

[24] The cost of labor input (management and non-management) in the *1997 Price Cap Review Order* is equal to wages and salaries expenses plus benefits expenses. This suggests that the lump-sum incentive payments would be recorded as labor costs. A key issue is a measurement problem since accounting data do not reflect the real cost accurately. To the extent that direct observations on labor input (*i.e.*, actual hours worked) are used, however, any disparities between accounting costs and real costs could be avoided. Unfortunately, labor input is not measured by the number of hours worked but as the total number of employees.

local output, and adjust the price of labor to reduce the effects of buyouts, is presented in Table B-12 in Appendix B.

While we have identified other potential sources of bias from the *1997 Price Cap Order* in our proposed recalculation of the X-factor, the 1999 staff TFP study does not adjust for them because they either are not easily quantified, or do not have a significant impact on the level of the X-factor. These other possible sources of bias are discussed below.

III. Other Possible Sources of Bias

The productivity offset or X-factor is given as

$$X(H) = (\%_\ TFP_{LEC}(H) - \%_\ TFP_{US}(H)) + (\%_\ IP_{US}(H) - \%_\ IP_{LEC}(H))$$

where X(H) denotes the historical X-factor, $\%_\ TFP_{LEC}(H)$ denotes the percent change in the historical total factor productivity of local exchange carriers between period t-1 and t,[25] $\%_\ TFP_{US}(H)$ denotes the percent change in the historical total factor productivity for the entire U.S. economy between period t-1 and t, $\%_\ IP_{US}$ denotes the percent change in the historical input prices of all goods and services used to produce output of goods and services in the United States between period t-1 and t, and $\%_\ IP_{LEC}$ denotes the percent change in the historical input prices of local exchange carriers used to produce local service, intrastate toll/access service, and interstate service between period t-1 and t.

It is important to note that there is no debate about whether there is appropriately an X-factor in the price cap equation nor is there a question about whether an input price differential should properly be included in the specification. The issue at hand is whether the components of the X-factor are accurately measured based on the data actually used in the computation. An assessment of this is the focus of what follows.

A. Biases in the Measurement of TFP_{LEC}

There are a number of biases inherent in the measurement of TFP_{LEC}. There are general biases and data-specific biases which will tend to overestimate or underestimate the true value of TFP_{LEC}.

i. General Biases

First, TFP_{LEC} will be biased since it is not compatible with incentives to be economically efficient because the disaggregated input and output data are under the control of the regulated LECs and, thus, are subject to manipulation. It has been noted that price cap regulation has the potential to introduce pure waste, inefficient factor utilization, excessive research and development expenses, and over-investment in demand increasing expenditures.[26] This will bias the measurement of TFP_{LEC} downward. The extent of

[25] Note that the time period subscripts are suppressed in order to facilitate the exposition.

[26] David E.M. Sappington, *Strategic Firm Behavior Under a Dynamic Regulatory Adjustment Process*, 11 Bell J. Econ. 360-72 (1980). Among the strategies identified by a firm to enhance long-run profits is the purchase of inputs that have no productive value. Other strategies include the acquisition of perquisites for executives of the firm, the employment of factors of production in inefficient combinations, and the allocation of excess funds to research and development.

this downward bias will be a function of the quantitative magnitude of any excessive expenditures and inefficient factor utilization.[27]

Another general bias introduced in the measurement of TFP_{LEC} is associated with the use of LEC performance data immediately post-divestiture. This will give a downward bias to the measure. It is generally conceded that under rate-of-return (ROR) regulation, regulated firms employed too much capital and too much labor. Transition from the regulated environment is not instantaneous. The optimal level of factors of production will be in disequilibrium for some period of time following the demise of ROR regulation. Hence, the measured TFP_{LEC} as reported in the *1997 Price Cap Review Order* will contain some disequilibrium periods.[28] That is, the measurement of the productivity of LECs is necessarily calculated, at least partially, in a ROR environment which will bias downward the TFP measure for at least a portion of the period.

A final general bias introduced in the measurement of TFP_{LEC} is associated with the demand for interstate access to local LECs' local loops. Interstate access service is the focus of price cap regulation. It has grown much more rapidly on average than demand for local service and intrastate access service. The data on this are clear. Thus, in the presence of economies of density,[29] this leads to the conclusion that TFP_{LEC} in interstate services has grown faster than company-wide (regulated) TFP_{LEC}.[30] More specifically, the price cap index (PCI) being considered here applies to interstate access service but TFP_{LEC} is computed based on all LEC services. There is every reason to expect that productivity enhancements experienced historically in the interstate access market would be substantially greater than the overall rate of productivity growth experienced by LECs in supplying all services. First, most of the productivity growth experienced in the telecommunications industry is related to reductions in switching costs and to savings in transmissions costs which occur as a result of using electronics to expand the carrying capacity of transmissions facilities. In contrast productivity growth in supplying loop services has been relatively lower. As a result of this, the average measure of TFP_{LEC} used in setting X and which should properly reflect productivity growth in the interstate access market is biased downward.

ii. Data-Specific Biases

a. Output Biases

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[27] This goes directly to the argument that an accurate measurement of TFP_{LEC} should not be used to adjust prices directly since full contemporaneous adjustment would diminish the LEC's incentive to conserve costs and operate efficiently. A full consideration of this issue, however, is outside the scope of the present discussion.

[28] An important assumption underlying any computation of TFP is that all inputs (factors of production) are in full static equilibrium. In many instances for local exchange carriers, however, the assumption of full static equilibrium is suspect and hence, so are the empirical results. Additionally, departures from full static equilibrium may result from factors other than internal adjustment costs. In the case of LECs, there is no evidence that capital stocks, for example, are completely adjusted at all times to cost-minimizing levels.

[29] Economies of density are a type of economies of scale that result in a decrease in unit cost of service that results from more intensive use of an existing facility's capacity.

[30] Richard T. Shin & John S. Ying, *Costly Gains to Breaking Up: LECs and the Baby Bells*, 98 Rev. Econ. & Stat. 357-61 (1993).

We turn now to specific issues involving the measurement of TFP_{LEC}. It is generally recognized that output growth is a key determinant of the rate of growth of TFP. Thus, it is especially important to measure it as precisely as possible.

Characterizing output is not a trivial undertaking. Output of telephone service includes both access and use. Access and use, however, are complicated by access and use externalities. The presence of these externalities means that, contrary to what is typically presumed, preferences are interdependent across subscribers. That is, as more users gain access to telephone, the utility of customers in the aggregate rises. These externalities are exceedingly difficult to quantify and are not measured here. This will bias downward the TFP_{LEC} measure. Additionally, output comes in a variety of forms including type (station, person, collect, etc.), time-of-day, day of week, distance, and duration.[31]

In the specification used, total company output consists of three identifiable components: local service, intrastate toll/access service, and interstate service. Revenue shares are used to weight each component's contribution to total output.

Each of the components in total company output is measured differently. This was dictated by the available data. It introduces a potential source of bias. The nature and extent of this bias, however, is indeterminate. That is, it is not clear whether there will be a positive or negative bias. This is an empirical issue. Since comparable measures are not available for each of the output components, it is not possible to measure it empirically.

The local service output measure is based on the number of local calls. Intrastate service output index is based just on the number of dial equipment minutes (DEMs) while the interstate service output index is a function the number of access lines, the number of switched access minutes, and the number of special access lines. No measure of special access minutes is used. It is interesting to note that the interstate output index endeavors to capture both the access and use components of interstate output. Output measures for local service and intrastate service do not endeavor to do so.

The component of the output measure that is probably the most questionable in the *1997 Price Cap Review Order* is the local service output index. This, however, has been corrected in the updated study.

b. Input Biases

We next consider the input (factors of production) side of measuring TFP_{LEC}. Before doing so, however, it is important to note that the cost of inputs (*i.e.*, the prices paid for inputs) in the TFP_{LEC} measurement also appear in the measurement of $\%_IP_{LEC}$. Hence, observations made concerning measurement errors and their impact on the computed value of TFP_{LEC} are equally applicable to the measurement of the percentage change in input prices of LECs. Furthermore, the nature of the relationship given by equation (1) means that most measurement errors associated with the prices of the inputs will tend to cancel out so that the impact on the productivity offset will, in general, be minimal.

[31] Lester D. Taylor, *Telecommunications Demand in Theory and Practice* (1994).

The most problematic input measure is that for the quantity of labor. Measurement of each input in a total factor productivity study typically requires subaggregation of various types of the factor. In the case of labor this would include several different occupational groups and skill levels and would be calibrated as the number of hours worked with appropriate adjustments for overtime and part-time workers. The labor quantity measure used in the *1997 Price Cap Review Order* consists solely of the total number of full-time employees of RBOCs. Thus, inherent productivity differentials between employees based on such things as skill levels is not reflected. If the LECs were in equilibrium such that the relative proportion of employees in the different occupational groups with defined skill levels characteristic of LECs remained unchanged as did the average number of hours each employee worked, then there would be little concern over how the labor variable is measured. This is not the case, however. Between 1985 and 1998, there was been a significant change in the number of employees. The LECs labor force declined by 2.4 percent annually over this period. Moreover, the reduction has taken place so that the number of managers has been reduced disproportionately more than the number of technical employees. Thus, there is a disparity between the change in observed labor versus effective labor.[32] The latter is what should be included in the measurement of TFP_{LEC} while the former is what has been included. Correct measurement of the labor variable would reduce aggregate labor expenses and hence increase TFP_{LEC}. Hence, as constructed, TFP_{LEC} is biased downward due to the incorrect measurement of the number of units of labor.

Materials quantity and materials expense are computed as residuals. Materials quantity is equal to materials expense divided by materials price. Materials expense is defined to equal total adjusted operating expense minus the sum of labor compensation, depreciation, and amortization expense. The increase in materials expense account for the major portion of the increase in total factor payment over the period 1985 to 1998. It is unclear whether there is a superior approach for measuring materials quantities and materials expense. The nature of any TFP_{LEC} measurement bias is uncertain.

The measurement of capital stock and the cost of capital was of greatest concern in the *1997 Price Cap Review Order*. Accurate measurement of capital stock is exceedingly difficult. Different types of capital with different vintages and technology comprise the stock in any given period. This stock, moreover, is subject to different utilization rates. With these difficulties come two significant problems[33] in the development of the measures of capital and the cost of capital that potentially serve to bias downward the reported measure of TFP_{LEC}. The first involves the changing quality of capital over the historical period that is not adequately reflected in the computations. The second involves changes in capacity utilization that are not captured.

The quantity of capital is measured for each depreciable asset by the perpetual inventory method from data on investment. Many types of capital inputs used by LECs have changed including computer chips, digital electronics, fiber optics, and digital switching equipment. This change in the quality of capital is not effectively reflected in the perpetual inventory approach adopted because the output associated with one unit of new capital brought on line is not necessarily equivalent to the output of one unit already in operation. If they are different, there has been a change in quality. The typical approach

[32] A discussion of this concept is included in Barbara J. Craig *et al.*, *International Productivity Patterns: Accounting for Input Quality, Infrastructure, and Research*, 79 Am. J. Agric. Econ. 1064-76 (1997).

[33] This is in addition to the one previously addressed involving the use of a competitively determined cost of capital.

to reflecting this quality change is to adjust the cost of capital downward to avoid understating the change in the effective level of real capital stocks.[34] Additionally, to the extent that succeeding generations of capital equipment are more productive, an appropriate adjustment to reflect this increases the computed level of capital stock, increases the flow of capital services, and, holding output constant, decreases the measured TFP_{LEC}. Since there was no quality adjustment in the computations reported in the *1997 Price Cap Review Order*, TFP_{LEC} will be biased upward.

The second significant omission is the failure to adjust for changes in capacity utilization. Over time as the existing capital stock is used more intensively, output is higher without a corresponding increase in capacity.[35] Consequently, TFP_{LEC} is greater. There is, however, no adjustment for a change in capacity utilization in the report. TFP_{LEC} will, consequently, be biased downward.

B. Biases in the Measurement of TFP_{US}

The measure of TFP_{US} used is the Bureau of Labor Statistics' estimate of Nonfarm Business Sector Multifactor Productivity.[36] There is concern that this measure underestimates the growth in TFP_{US}. There is, however, no basis for determining the magnitude of the underestimation although the consensus is that it is relatively small.[37] This being the case, while the productivity offset will be overestimated, its size is small but indeterminate.

The major issues related to the BLS measure of productivity that potentially give rise to overestimation of TFP_{US} include:

(1) Mismeasurement of productivity growth in the services portion of the economy. This portion of the economy is defined to include communications. The problem centers on how to define output in the service-producing industries. In the case of the services provided by LECs, this can be thought of as measuring output in terms of access and use. There is an enormous literature on the mechanics of defining output in these service-producing industries although there is no consensus on how this should be done. Inadequate definitions of output underlie the published data for many service activities.

(2) Biases in the Consumer Price Index (CPI) on productivity data. Components of the CPI are used to construct approximately 57 percent of the business sector output measure used for BLS productivity statistics. Thus, any biases in constructing the CPI are directly reflected in TFP_{US}. Biases in the CPI are well documented although their precise magnitude is subject to debate.[38] These biases include incorrectly

[34] Jack E. Triplett, *High-Tech Industry Productivity and Hedonic Prices*, Industry Productivity, OECD, 119-42 (Paris, 1996).

[35] Ernst R. Berndt & Melvyn A. Fuss, *Productivity Measurement with Adjustments for Variations in Capacity Utilization and Other Forms of Temporary Equilibrium*, 33 J. Econometrics 7-29 (1986).

[36] Note that the Bureau of Labor Statistics refers to total factor productivity as multifactor productivity.

[37] Edwin R. Dean, *The Accuracy of the BLS Productivity Measures*, 122 Monthly Lab. Rev. 24-34 (1999).

[38] *See, for example, Toward a More Accurate Measure of the Cost of Living*, Final Report to the Senate Finance Committee from the Advisory Commission to Study the Consumer Price Index, U.S. Senate Committee on Finance, (Dec. 1996).

reflecting the substitution bias where consumers' tendencies to substitute among items or categories of items as relative prices change over time, failure to capture new-outlet bias where consumers respond to relative price changes by shopping at different retail outlets, and inadequately measuring quality changes and new products reflecting changes in technology and consumer demand.

(3) Whether the BLS productivity data fully reflect changes in the quality of goods and services. Questions persist as to whether the total factor productivity measure for the United States economy reflect the extent that succeeding generations of capital equipment are more productive and hence whether an appropriate adjustment to reflect has been incorporated. Note that this will increase the computed level of capital stock and increase the flow of capital services.

(4) Whether the best techniques are used to introduce new, advanced products into the data series.

(5) Whether the BLS methods capture the full impact of new information technology on economic performance. It has been suggested, for example, that failure to adequately reflect information technology understates TFP_{US}.[39]

These issues are discussed fully in a series of articles in the February 1998 issue of the *Monthly Labor Review.*

One other source of bias not previously noted is also present. This involves composition changes in inputs. In the case of labor composition, changes include increased educational attainment over time which increases TFP_{US} and an increased share of teenagers and females in the labor force which reduces TFP_{US}.[40] In the case of capital, there has been continuous substitution of equipment for structures and of short-lived equipment like computers for long-lived equipment like furniture. Failure to reflect this substitution underestimates the capital stock component of the TFP_{US} measure.

C. Biases in the Measurement of IP_{US}

The general input price measure used is the Bureau of Labor Statistics Nonfarm Business Sector Price Index. The sources of the data used in constructing this measure are the same as those for the BLS measure of TFP_{US}. Consequently, the major issues related to the BLS measure of TFP_{US} are applicable to the measurement of IP_{US}.[41] These include the question of how to define output in service-producing industries, the biases present in constructing the Consumer Price Index, the issue of the introduction of new, improved factors of production, and the effect of quality changes in goods and services used in production.

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[39] Dale W. Jorgenson and Kevin J. Stiroh, *Information Technology and Growth*, 89 Am. Econ. Rev. 109-15 (1999).

[40] Robert J. Gordon, *U.S. Economic Growth Since 1870: One Big Wave?*, 89 Am. Econ. Rev. 123-28 (1999).

[41] Lucy P. Eldridge, *How Price Indexes Affect BLS Productivity Measures*, 122 Monthly Lab. Rev. 35-46 (1999).

While there are biases in the measure of IP_{US} due to biases in its components, considered together with any bias in the measure of TFP_{US} attributable to input prices would most likely have an insignificant net effect on the productivity offset. For example, an increase in the price of one of the factor inputs will lower TFP_{US} but it will increase the input price differential resulting in little net change in X.

D. Biases in the Measurement of IP_{LEC}

The measure of IP_{LEC} is a composite index using the labor price index, a materials price index, and a cost of capital index. The biases introduced were previously noted in the context of measuring TFP_{LEC} including changes in the quality of capital and capacity utilization variations. The effective price of labor is probably overestimated while the cost of capital even after adjustment to reflect competitive conditions might or might not be correct. An adjustment in the cost of capital to reflect changes in quality would increase the price while an adjustment to reflect changes in capacity utilization would reduce the price.

As noted previously, there are obvious upward biases in the measure of IP_{LEC} due to biases in its components. This, however, considered in conjunction with the bias in the measure of TFP_{LEC} attributable to these input prices results in a minimal net effect on the productivity offset (X-factor). That is, increasing (decreasing) the price of one of the factor inputs will lower (raise) TFP_{LEC} but it will reduce (raise) the input price differential resulting in little net change in X.

IV. Conclusion

Based on the above analysis, the X-factor calculated in the 1997 Staff TFP Study is a significantly downward biased estimator of the actual rate of cost reductions achieved by the price cap LECs. The residual value method employed in this study inappropriately incorporated the steadily rising profits of LECs into increases in the cost of the capital input.
Correction of the LECs' historical cost of capital plus the change in the local output measure results in a somewhat larger absolute value of the X-factor than the Commission computed in the 1997 staff TFP study.[42] Over the 1986-1995 period, for example, we compute the average X-factor to be 5.82 versus an average of 5.23 from the 1997 staff TFP study. Between 1991 and 1995, when price caps were in effect, our corrected average X-factor is 6.14 versus an average of 5.22 from the 1997 staff TFP study. Also, there is somewhat more year-to-year variation in our corrected X-factor than there is in the 1997 staff TFP study.[43] Using data covering the period 1986 to 1998, the updated X-factor is 6.02 while for the 1991 to 1998 period, the X-factor is 6.33.

[42] The recalculated X-factor is in column I of Table B-12 in Appendix B.

[43] Column I of Table B-12 in Appendix B shows the variance in the X-factor series for our corrected X-factor and the X-factor in the 1997 staff TFP study.

Appendix B

The 1999 Staff TFP Study

Noel D. Uri

Introduction

Under price cap regulation, the weighted average of the prices for the services in a given price cap, or the actual price index (API), must be less than or equal to the price cap index. An incumbent LEC's Price Cap Index (PCI) is adjusted annually in accordance with the PCI relationship defined in the *Code of Federal Regulations*.[1] The PCI relationship consists of a measure of inflation, in this case the Gross Domestic Product Price Index (GDP-PI), minus the X-factor, plus or minus any permitted exogenous cost changes. The X-factor is nominally referred to as the productivity offset.

The X-factor is defined to equal the sum of the change in LECs' productivity less the change in productivity of the aggregate economy plus the change in input prices for the aggregate economy less the change in LECs' input prices. In the *1997 Price Cap Review Order*,[2] a total factor productivity (TFP) approach was adopted for estimating LECs change in productivity.

Considerable thought has gone into and extensive comments were made concerning the selection of a technique to calibrate the X-factor.[3] This decision process will not be revisited. Rather, the immediate concern is with measuring the X-factor based on the most recent, consistent, and comprehensive data generally and publicly available.

Background

The methodology used by the FCC's staff to estimate LEC Total Factor Productivity (TFP) and the input prices, and to calculate the LEC TFP and input price differentials used in the FCC's LEC X-factor for interstate access is discussed here. TFP is calculated based on the LECs regulated books of account excluding miscellaneous services. Thus, the measure of total factor productivity is based on the productivity of all LEC activities including local service, intrastate toll/access service, and interstate service. The calculations are for the period 1985 through 1998.[4]

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[1] Section 61.45 (b) of the Commission's rules, 47 C.F.R. § 61.45(b).

[2] *Price Cap Performance Review for Local Exchange Carriers*, Fourth Report and Order in CC Docket No. 94-1 and Second Report and Order in CC Docket No. 96-262, 12 FCC Rcd 16642, 16645 (1997) ("*1997 Price Cap Review Order*").

[3] Much of this is recounted in the *1997 Price Cap Review Order*.

[4] The X-factor actually relies on changes in TFP. The discussion, however, is in terms of TFP levels from which changes are derived.

The calculations are based on the Fisher Ideal Index, a standard and economically justifiable measure. The TFP estimates embody what is believed to be the best approach available for measuring the X-factor and emulates the approach used in *1997 Price Cap Review Order*.

The study is based on data publicly available from the Federal Communications Commission, the Bureau of Economic Analysis of the U.S. Department of Commerce, and the Bureau of Labor Statistics of the U.S. Department of Labor. Consistent with the *1997 Price Cap Review Order*, the data are for just the Regional Bell Operating Companies (RBOCs).

Methodological Issues

A productivity index is generally defined as an output index divided by an input index.[5] An important question is which functional form for the index number should be used. Here, known functional forms for index numbers are related to functional forms for the underlying aggregator function.

Two important examples of a quantity index are the Laspeyres and Paasche index. The Laspeyres quantity index, Q_L, is defined as

(1) $Q^L (p^0, p^1, x^0, x^1) = p^0 x^1 / p^0 x^0$

where $p^t > 0$ is a vector of prices in period $t = 0, 1$ and $x > 0$ is the corresponding vector of quantities. The Paasche quantity index, Q_P, is defined as

(2) $Q^P (p^0, p^1, x^0, x^1) = p^1 x^1 / p^1 x^0$.

Fisher[6] suggested that the Ideal Index is given as the geometric mean of Q_L and Q_P

(3) $Q^F (p^0, p^1, x^0, x^1) = ((p^0 x^1 / p^0 x^0) (p^1 x^1 / p^1 x^0))^{1/2}$.

Let f(x) define an aggregator function and suppose that $x^t > 0$ is the solution to

(4) $\max_x \{f(x): p^t x \leq p^t x^t\}$ t=0, 1

where $f(x) = (x'Ax)^{1/2}$ and $A = [a_{ij}]$ is a symmetric matrix of coefficients. Konus[7] then shows that

(5) $f(x^1) / f(x^0) = Q^F (p^0, p^1, x^0, x^1)$.

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[5] The theory of total factor productivity and the requisite use of productivity indexes in measuring productivity change is fully developed in Dale W. Jorgenson and Zvi Griliches, *The Explanation of Productivity Change*, 34 Rev. Econ. Stud. 249-83 (1967).

[6] Irving Fisher, *The Making of Index Numbers* (1922).

[7] Alexander A. Konus, *The Problem of the True Cost of Living*, 7 Econometrica 10-29 (1939).

If a quantity index Q^F (p^0, p^1, x^0, x^1) and a functional form aggregator function f satisfy (5), then the quantity index Q^F is said to be exact for the aggregator function. Konus shows that the Laspeyres quantity index is exact for a fixed aggregator function while the Paasche quantity index is exact for a linear aggregator function. Afriat,[8] Diewert,[9] Pollack,[10] and Samuelson and Swamy[11] provide other examples of exact index numbers. Among exact index numbers, however, the Fisher quantity index corresponds to a functional form for f that can provide a second order approximation to an arbitrary twice-differentiable linearly homogeneous function. Thus, the use of the Fisher Ideal Index is economically justified.[12]

The input and output quantity indices are constructed using the Fisher Ideal Index. As noted, this index is the geometric average of the Laspeyres Index and the Paasche Index. This index is desirable because it is calculated using the weights of adjacent years. During periods of relatively substantial and significant changes in prices, a significant bias can appear in fixed weight measures, even during periods close to the base period.[13]

Expanding beyond just two periods, a chained Fisher Ideal Quantity Index can be constructed between periods 0 and t. It is the product of each of the Fisher Ideal Quantity Indexes between periods 0 and t. All input and output quantity indexes are chained Fisher Ideal Quantity Indexes. The chained Fisher Ideal Quantity Index addresses one of the most fundamental problems in measuring output - the choice of the base period with which all other periods are compared. Since changes in the Fisher Ideal Quantity Index are calculated using weights of adjacent years, the chaining of the annual changes allows for the effect of changes in relative prices. Thus, the Fisher Ideal Chained Quantity Index calculates an index that is appropriate for each period and avoids having to update a fixed-weight index. It also negates the substitution bias that is inherent in a fixed-weight index.[14] Finally, the chain-type index provides a more accurate measure of current period output during periods of significant price changes.[15]

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[8] S.N. Afriat, *The Theory of International Comparisons of Real Income and Prices*, International Comparisons of Prices and Quantities, (David J. Daly ed. 1972).

[9] W. Erwin Diewert, *Exact and Superlative Index Numbers*, 4 J. Econ. 115-46 (1976).

[10] Richard Pollack, *The Theory of the Cost of Living Index*, (1971).

[11] Paul A. Samuelson and Subramanian Swamy, *Invariant Economic Index Numbers and Canonical Duality: Survey and Synthesis*, 64 Am. Econ. Rev. 566-93 (1974).

[12] For more on the properties of this index see W. Erwin Diewert, *The Economic Theory of Index Numbers: A Survey*, Essays in the Theory and Measurement of Consumer Behavior, (Angus Deaton ed. 1980); and S.N. Afriat, *The Price Index* (1977).

[13] Robert P. Parker and Jack E. Triplett, *Chain-Type Measures of Real Output and Prices in the U.S. National Income and Product Accounts: An Update*, Bus. Econ. 2-7 (Oct. 1996).

[14] Franklin M. Fisher and Karl Shell, *Economic Theory of Price Indices* (1972).

[15] J. Steven Landefeld and Robert P. Parker, *BEA's Chain Indexes, Time Series, and Measures of Long-Term Economic Growth*, 77 Survey of Current Bus. 58-68 (1997).

Indexes of input prices are constructed in a fashion analogous to that for the input and output quantity indexes. That is, by calculating a Fisher Ideal Price Index.

The Laspeyres price index, P_L, is defined as

(6) $P^L (p^0, p^1, x^0, x^1) = p^1 x^0 / p^0 x^0$

where $p^t > 0$ is a vector of prices in period t = 0,1 and x > 0 is the corresponding vector of quantities. The Paasche price index, P_P, is defined as

(7) $P^P (p^0, p^1, x^0, x^1) = p^1 x^1 / p^0 x^1$.

The Fisher Ideal Index for prices is given as the geometric mean of P_L and P_P

(8) $P^F (p^0, p^1, x^0, x^1) = ((p^1 x^0 / p^0 x^0) (p^1 x^1 / p_0 x^1))^{1/2}$.

A chained Fisher Ideal Price Index can be constructed between periods 0 and t. It is the product of each of the Fisher Ideal Price Indexes between periods 0 and t. All input price indexes are chained Fisher Ideal Price Indexes. As is the case for output and input indexes, a chained price index is superior to a fixed-weight index.

Aggregating across different types of outputs to construct the Fisher Ideal Quantity Index for output in a given period is accomplished by using the relevant commodity share of total revenue corresponding the type of output. Aggregating across the different factors of production to construct the input quantity and input price indexes in a given period is accomplished by using the relevant shares of total payments to the corresponding factors.

Calculation of Output Quantity Indexes

(a) Data Sources

The output index is based on actual quantity measures available from the Commission. Basic local service revenue, end user revenue, switched access revenue, special access revenue, state access revenue, and total long distance network revenue are taken from the Commission's Statistics of Communications Common Carriers for 1985 through 1998. Also taken from this source are data on the number of special access lines, the number of business access lines, residential access lines, and public access lines. Local access volume is measured by the number of local dial equipment minutes as are state toll and intrastate access volumes by dial equipment minutes. These data are taken from the FCC Monitoring Reports. They are directly accessible via the FCC web site.[16] Interstate switched access minutes are from the same Monitoring Reports. The component data for interstate revenue are given in are given in Table B-1. Total revenue data for each type of service are given in Table B-2.

(b) Output Category Quantity Indices and Revenue Shares

[16] http://www.fcc.gov

The initial step in the process is to construct an interstate quantity index to measure growth of interstate services. This index is constructed using the physical measures of three services including the number of access lines, the number of interstate switched access minutes, and the number interstate special access lines. The number of access lines is measured by the sum of the number of business, public, and residential access lines.

A service's share of total interstate revenue is used to weigh each service in the construction of the measure of interstate output. That is, the number of access lines is weighted by the End User Common Line revenue share of total interstate revenues. The number of switched access minutes is weighted by the switched access revenue share, and the number of special access lines is weighted by the special access revenue share. A Fisher Ideal Quantity Index is then constructed. The composite Fisher Ideal Interstate Quantity (Output) Index is derived by chaining the Fisher Interstate Ideal Output Index. The resulting Fisher Ideal Chained Output Index is given in Table B-3.

A comparable procedure is used to construct revenue shares and quantity indices for total local service and state toll/access service. State toll/access revenues are total toll service revenues plus intrastate access revenues. The physical units associated with total local service are the number of dial equipment minutes for local calls while for state toll/access service, the physical units are intrastate dial equipment minutes. These data are taken from the FCC Monitoring Reports.[17]

(c) Total Output Index

The total LEC output index is computed using the quantity indexes for local service, intrastate toll/access service, and interstate service and their respective revenue shares. The interstate share of total revenue is calculated using the sum of end user revenue, switched access revenue (formerly called "carrier's carrier facilities revenues"), and interstate special access revenue. A Fisher Ideal Quantity (Output) Index is constructed by aggregating these measures for each year. The composite Fisher Ideal Output Index is derived by chaining the Fisher Ideal Output Index. The resulting Fisher Ideal Chained Output Index for total LEC output is given in Table B-4. Note that the percentage changes (growth rate) are calculated as natural logarithmic ($\log_e$) changes.

Calculation of Input Quantity Indexes

(a) Labor

The measure of the quantity labor is based on annual accounting data for the number of employees from the Commission's *Statistics of Communications Common Carriers*. These data are reported in Table B-5. Since there is no objective way to account for the contribution of part-time versus

[17] Data for local DEMs and intrastate DEMs for 1998 are not yet available. They are forecast using simple exponential extrapolations. Because local DEMs exhibit an identifiable structural shift beginning in 1992 associated with increased Internet access, data for 1992 to 1997 only are fit to a time trend and then forecast. After correction for the ubiquitous first order serial correlation ever-present in these sorts of relationships, the resulting coefficient of determination is 0.97. Data for years prior to 1992 were not considered because the adjustments necessary in the extrapolation specification would negate any benefits associated with the added degrees of freedom. For intrastate DEMs, there was no structural shift in the functional relationship so data for the entire 1985 to 1997 period was used. The resulting coefficient of determination is 0.99 after correction for first order serial correlation.

full-time employees, just the total number of employees is used as the labor input measure. This, however, does not introduce a substantial bias in the labor quantity measure since part-time employees accounted for less that 0.7 percent of the workforce in 1998.

(b) Capital

(i) Perpetual Inventory Method

The starting point for construction of a quantity index of capital input is the measurement of the capital stock. A perpetual inventory method is employed to estimate the level of capital stock.[18] In discrete time, the method is

(9) $K_t = I_t + (1 - \delta) K_{t-1}$

where K_t is the end-of-period capital stock, I_t is the quantity of investment occurring in the period, and δ is the rate of replacement (depreciation). The data requirements for implementation of this perpetual inventory method are investment in constant (inflation-adjusted) prices, a capital benchmark, and a rate of replacement.

The perpetual inventory method is used to remove embedded inflation that would distort the measurement of capital. Consistent with the *1997 Price Cap Review Order*, only one asset class is considered because the record shows that the number of asset classes does not significantly impact the measured change in TFP. The application of the perpetual inventory model relies on Commission depreciation rates.

The book value of plant is used as the basis for calculating the benchmark (*i.e.* initial level) capital stock. In order to calculate constant dollar investment, chained Fisher asset prices from the Bureau of Economic Analysis of the U.S. Department of Commerce are used deflate capital additions.

The benchmark capital stock is based on the end of year 1985 book value. Because of the 1988 capital/expense shift, it is necessary to adjust both end of year 1985 total plant in service less accumulated depreciation and 1985-1987 capital additions. The capital/expense shift factor used in the *1997 Price Cap Review Order* is employed here to reduce capital additions for 1985 through 1987. Adjusted capital additions for 1985, 1986, and 1987 are just the product of the unadjusted capital additions and the adjustment factor of 0.888. Unadjusted capital addition data were obtained from FCC Form M.

(ii) Asset Price

With just a single asset class, a single composite asset price index is needed. First, Bureau of Economic Analysis asset prices were obtained from the National Income and Product Accounts. These included prices for three asset categories including Communications Equipment (NIPA[19] Table 7.8:

[18] Raymond W. Goldsmith, *A Perpetual Inventory of National Wealth*, Studies in Income and Wealth, (1951).

[19] National Income and Product Accounts complied by the Bureau of Economic Analysis of the U.S. Department of Commerce.

Chained-Type Price indexes for Private Purchases of Producers' Durable Equipment by Type, Line 7), Telecommunication Structures (NIPA Table 7.7: Chained-Type Price Indexes for Private Purchases of Structure by Type, Line 12), and a composite asset price for Producer Durables (NIPA Table 7.1, Line 39). Capital additions data are then grouped into categories corresponding to the NIPA asset categories, and each category's share calculated. (The capital/expense shift adjustment factor noted previously has no effect on the shares because it is multiplicative and applies equally to all asset categories.)

From these data, a Fisher Ideal Price Index is computed and used to form a chained Fisher Ideal Price Index for the single asset. This price index is used to deflate adjusted capital additions in the perpetual inventory model.

(iii) Benchmark Capital Stock

The benchmark capital stock is derived using the FCC accounting relationship

(10) $TPIS.BOY_t + CA_t - Retires_t = TPIS.EOY_t$

where $TPIS.BOY_t$ denotes beginning of the year total plant-in-service for period t, CA_t denotes capital additions in period t, $Retires_t$ denotes plant retirements in period t, and $TPIS.EOY_t$ denotes total plant-in-service at the end of the year for period t. All of these data are taken from the FCC Form M.

Adjusted capital additions are incorporated which results in revised values for $TPIS.EOY_t$ for 1985, 1986, and 1987. The benchmark capital stock is then obtained by subtracting accumulated depreciation from adjusted $TPIS.BOY_{1985}$.

As is standard practice in most TFP studies,[20] land is not included as a capital stock component when forming the benchmark capital stock.

(iv) Depreciation Rate

A time-invariant depreciation rate for the single asset class is computed as an arithmetic average of annual depreciation rates. The depreciation rate for period t is given as

(11) $\delta_t = (DEPR.ACRLS_t) / ((TPIS.BOY_t + TPIS.EOY_t)/2)$.

where $DEPR.ACRLS_t$ denotes depreciation accruals. The data are taken from FCC Form M.

The value of δ is the average (mean) value of δ_t over the period 1985-1998.

A summary of capital adjustments and average depreciation is given in Table B-6.

(v) Capital Input Quantity Index

[20] Land is typically omitted from consideration in TFP studies with the exception of those dealing with agriculture. This is more fully explored in V. Eldon Ball *et al.*, *Agricultural Productivity Revisited*, 79 Am. J. Agric. Econ. 1045-63 (1997).

The capital input quantity index series is computed by dividing current period capital stock by the base period capital stock. These data are reported in Table B-7.

(c) Materials - Part I

The materials quantity is computed as materials expense divided by a materials price index. Materials expense is a residual. It is the difference between total operating expense and the sum of labor compensation and depreciation and amortization expense.[21]

Until now computation of the various components of the X-factor have been straightforward and mechanistic. Things are somewhat more complicated, however, from this point forward. To explain the complications and what is necessary to compute materials quantity, a digression is in order.

(d) Digression

TFP models in general measure productivity as the ratio of an index of outputs of a firm to an index of its inputs over a given time period (e.g., a year). The growth in productivity is the amount by which this ratio changes over time. In making these calculations, it is critical that real changes in productivity be separated from the effects of changes in input prices.

It is typically the case that three inputs are considered in TFP-type studies. These inputs consist of labor, capital, and materials.[22] Sometimes a fourth input—energy—is considered. This is not done here. When just three inputs are used in the analysis, materials is considered as a residual. That is, it accounts for whatever input expenditures are not attributable to labor and capital.

The growth rate of the index of inputs is determined by the growth rates of the labor, capital, and materials input indices weighted by their relative contribution to total input cost. The growth rate of capital is a complex procedure, requiring a determination of capital stock and the flow of capital services from capital stock.

A number of very explicit assumptions underlie TFP analyses. In particular, the conventional method of measuring TFP of firms (which is used in the *1997 Price Cap Review Order*) is to assume that there are constant returns to scale and that observed inputs and outputs have been generated by firms in competitive, long run equilibrium. With prices of output and inputs fixed, the firm chooses input levels

[21] Materials expenses for 1985 through 1987 must be adjusted for two accounting changes that became effective in 1988. First, beginning in 1988 all expenses from nonregulated services that had joint and common costs with regulated services were reported in operating expenses. Second, certain plant investments that formerly were capitalized began to be expensed in the year they were incurred. Accordingly expenses for 1985 through 1987 were adjusted upward to put them on a basis comparable to the accounting expense recorded from 1988 onward. The adjustment factor is computed by dividing the sum of annual reported operating expense plus the additional materials expense resulting from both the regulated/nonregulated change and the capital/expense shift by reported operating expenses for the years 1985-1987. These percentages are used to adjust 1985 through 1987 operating expenses of the LECs.

[22] Dale W. Jorgenson *et al.*, *Productivity and U.S. Economic Growth* (1987).

so as to maximize profit.[23] The measure of TFP growth obtained by conventional means is not, however, appropriate whenever firms are not in a long run cost minimizing equilibrium. A firm is not in long run equilibrium whenever the firm's input-output bundle is other than corresponding to a point on the long run unit cost curve. If the firm is not in long run equilibrium, then profit is not zero.[24]

Before exploring the implications of this observation for the results reported in the *1997 Price Cap Review Order*, it is necessary to examine what price caps are and to assess the mechanics of estimating an historical productivity offset.

(i) Price Caps in Theory

Overview

Assume that there are two periods, $t = 1,2$. Suppose that in each period the firm produces units of a single output, q_t, using a single input which will be called labor and denoted by L_t.[25] Let w_t denote the price of labor in period t and p_t denote the price of output in period t. An outcome for the market in period t is defined to be a vector of these four variables, (p_t, q_t, w_t, L_t). If the output price of the firm is regulated so that its revenues equal its costs, then the outcome in each period will satisfy

(12) $p_t = w_t L_t / q_t$.

Define the variable z_t to be the productivity of the firm in period t measured in units of output per units of input. Thus,

(13) $z_t = q_t / w_t$.

Substitution of relationship (13) into relationship (12) yields

(14) $p_t = w_t / z_t$.

That is, in a regulated market where the firm is constrained to earn zero economic profit, the output price will be equal to the input price divided by productivity.

Use the following notation to denote the percentage change in each variable between periods 1 and 2:

(15) $\%\Delta p = (p_2 - p_1)/p_1$

[23] *See, e.g.*, Ernst R. Berndt and Melvyn A. Fuss, *Productivity Measurement with Adjustments for Variations in Capacity Utilization and Other Forms of Temporary Equilibrium*, 33 J. Econ. 7-29 (1986); *and* Dale W. Jorgenson and Zvi Griliches, *The Explanation of Productivity Change*, 34 Rev. Econ. Stud., Vol. 249-83 (1967).

[24] Michael A. Crew and Paul R. Kleindorfer, *Incentive Regulation in the United Kingdom and the United States: Some Lessons*, 9 J. Reg. Econ. 211-25 (1996).

[25] Nothing changes if both output and input are viewed as consisting of baskets of goods. Inputs and outputs are considered here as single entities to simplify the exposition.

(16) $\%\Delta q = (q_2 - q_1)/q_1$

(17) $\%\Delta pw = (w_2 - w_1)/w_1$

(18) $\%\Delta L = (L_2 - L_1)/L_1$

(19) $\%\Delta z = (z_2 - z_1)/z_1$

It follows immediately from equation (14) that when outcomes in both periods are regulated so that the firm earns zero economic profit, then

(20) $\%\Delta p = \%\Delta w - \%\Delta z$.

That is, if the firm is constrained to earn zero economic profit, then the percentage change in output price will just equal the percentage change in input price minus the percentage change in productivity.

Price Caps With an Exogenous Input Price Index

The well-understood problem with cost-based regulation is that the regulated firm has very little incentive to be efficient because any efficiency gains are immediately captured by the regulator. Price caps are meant to ameliorate this problem. The basic idea is very simple. Suppose that period 1 has just ended and the regulator is considering how to set price in period 2. The regulator knows that if he or she uses cost-based regulation to set price in period 2 that the resulting price will satisfy relationship (9). The essential idea of price caps is to replace the term $\%\Delta z$ with an estimate of $\%\Delta z$ made in period 1. Let E denote the estimate of productivity change. At the end of period 1, it is announced that the price in period 2 will be set according to the formula

(21) $\%\Delta p = \%\Delta w - E$.

That is, the regulator will wait until the end of period 1 and observe the actual change in input prices and allow output prices to increase by this percentage. Rather than wait to observe actual changes in productivity, however, the output prices are adjusted by a fixed amount regardless of the firm's realized productivity change.

The firm will then earn a normal profit (and zero economic profit) if the regulator is able to correctly guess the actual (realized) productivity change. The firm will have a strong incentive, however, to improve productivity because it will keep any positive or negative profits that result if its actual productivity improvement is different than the predicted productivity change.

One could also imagine the regulator replacing $\%\Delta w$ with an exogenous, pre-specified estimate. Then the regulator would simply tell the regulated firm that its output prices would change by a certain percent regardless of the level of actual input price inflation in period 2. This practice is not usually followed, however, because the regulated firm typically purchases inputs in relatively competitive markets so that the regulated firm has very little influence over the price it pays for inputs. Therefore, exogenously pre-specifying a target percentage change for input prices would have no desirable incentive

effects. It would increase the risk, however, that the regulated firm is required to incur to the extent that future input prices vary unpredictably. Therefore, $\%\Delta$ w is not typically replaced by a pre-specified estimate.

Price Caps With An Exogenous National Output Price Index

Price cap schemes generally have the form that output price is allowed to increase in a given year by the amount that some price index actually increases minus some pre-specified amount. The foregoing section suggests that a very simple, transparent, and straightforward method for implementing a price cap system would be to base the price index on **INPUT** prices for the industry being regulated. This practice, however, is not typically followed. Rather, instead of basing the price index on **INPUT** prices for the industry being regulated, regulators generally use a composite price index for **OUTPUT** prices for the economy as a whole. In particular, this is the practice followed by the Federal Communications Commission (hereafter Commission) to regulate interstate access prices.

When a national output index is substituted for an industry input index, a correction has to be made for the fact that input prices in the particular industry being regulated may be systematically growing at a different rate than output prices in the economy as a whole. For example, because of rapid technological advances in telecommunications, input prices for telecommunications firms are not changing at the same rate as output prices in the economy. Consequently, the regulator must choose an adjustment factor to correct for this difference. Let D denote the regulator's estimate of the rate at which output prices in the economy as a whole change differently than input prices in the regulated industry. Let RPI denote the percentage change in the national output price index. The price cap formula becomes

(22) $\%\Delta\, p = RPI - D - E$.

This can be rewritten as

(23) $\%\Delta\, p = RPI - X$

where

(24) $X = D + E$.

This is the familiar form of a price cap plan. That is, the X-factor is composed of two separate components. It is the sum of the predicted productivity growth of the regulated firm, E, plus the expected amount that national output prices grow faster than industry input prices, D.

Choosing the X-Factor

The efficiency incentives created by a price cap scheme are not affected by the size of the X-factor that the regulator chooses. The simple fact that the X-factor is fixed and independent of the actual costs incurred creates an incentive for the firm to be efficient. The regulator is still concerned with the level of the X-factor, however, because this affects the distribution of the economic surplus between the firm and consumers. It can also potentially affect whether or not the regulated firm chooses to exit the industry. If the X-factor is chosen too high, the regulated firm may well choose to exit the industry. On the other hand, if it is chosen too low, the regulated firm will earn positive economic profit and consumers will pay higher prices than necessary. Therefore, the regulator has a considerable interest in choosing an

X-factor so that it will be above but as close as possible to the sum of the expected value of the firm's productivity change and the difference between the industry's input price change and the economy's output price change.

One relevant piece of information is the behavior of these variables in the recent past.[26] Let E_H denote the historical rate of productivity growth for the regulated firm over the recent past. Let D_H denote the historical difference between the rate of change in output prices for the economy as a whole and the rate of change of input prices for the regulated industry. Let X_H denote the sum of these two variables. That is,

(25) $X_H = D_H + E_H$.

The variable X_H will be referred to as the historically justified X-factor. The typical practice of regulators is to calculate the historically justified X-factor and then to set the X-factor equal to this unless factors can be identified which will cause the future values to depart systematically from the historical values. If so, some attempt must be made to adjust exogenously for such factors.

These identifiable factors are customarily most important when price caps are being first introduced to replace rate-of-return regulation. In such a circumstance, it is generally argued that the increased efficiency incentives created by the switch to price caps will result in higher future rates of productivity growth than were historically observed. Therefore, it is argued that future productivity growth is likely to be higher than past productivity growth for some period of time.[27] Therefore, when price caps are first introduced, regulators often set the X-factor somewhat higher than the historically justified rate in anticipation of increased production efficiency. The Commission followed this practice when it first introduced price caps for LECs in 1991. The actual X-factor was set 0.5 percent above the historically justified level and this difference was nominally referred to as the consumer productivity dividend.

Note, however, that increased efficiency incentives created by the switch to price caps will dissipate when price caps have been in effect for some time and the historical period being evaluated is one where price caps were in place.[28] In this case, the historical data are already reflecting the increased incentives for efficiency created by price caps.

In theory it is possible to imagine all sorts of reasons why future rates of productivity growth may diverge from past rates, even if price caps have been in place for some time.[29] For example, one of the

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[26] David E.M. Sappington, *Strategic Firm Behavior under a Dynamic Regulatory Adjustment Process*, 11 Bell J. Econ. 360-72 (1980).

[27] In fact if this were not true, there would be no reason to implement price caps in the first place.

[28] David P. Baron, *Information, Incentives, and Commitment in Regulatory Mechanisms: Regulatory Innovation in Telecommunications*, 6 Price Caps and Incentive Regulation in Telecommunications (Michael A. Einhorn ed. 1991).

[29] A number of these reasons are explored in, e.g., Ferenc Kiss, *Productivity Gains in Bell Canada*, in Economic Analysis of Telecommunications: Theory and Applications (Leon Courville *et al.* eds. 1983); and Donald (continued . . .)

main sources of measured productivity growth is simply growth in demand, since production technologies of regulated firms frequently exhibit economies of scale. Therefore, if the estimated rate of demand growth in the future is different than the historical rate of demand growth, this would create a basis for predicting a difference between historical and future rates of productivity growth.

In practice, however, regulators' information is often much too unreliable to attempt to make such corrections. Consequently, in many regulated industries it may be that the only course of action on the part of the regulator than can withstand a critical challenge is for the regulator to set the future X-factor equal to the historical rate.

There is some evidence that the Commission is in fact in this position. In the *1997 Price Cap Review Order*, the Commission calculated that the historically justified X-factor was approximately 5.2 percent but then attempted to argue that the future X-factor should be set at 6.0 percent. The U.S. Court of Appeals for the D.C. Circuit recently remanded this decision to the Commission, stating that the Commission had not adequately justified the additional amount to the historically justified rate.

(i) Price Caps in Theory and Practice

The Commission's description of its methodology for calculating the historically justified X-factor in the *1997 Price Cap Review Order* appears to be different than the procedure for estimating the D_H and E_H described above. This difference, however, is only superficial. The procedure used by the Commission to estimate X_H is, in fact, precisely as described above. This is explained in what follows.

In the description of its procedure in the *1997 Price Cap Review Order*, the Commission states that it calculates the historically justified X-factor according to the following formula:

$$(26)\ X(H) = (\%\Delta\ TFP_{LEC}(H) - \%\Delta\ TFP_{US}(H)) + (\%\Delta\ IP_{US}(H) - \%\Delta\ IP_{LEC}(H))$$

where X(H) denotes the historical X-factor, $\%\Delta\ TFP_{LEC}(H)$ denotes the percent change in the historical total factor productivity of local exchange carriers between period t-1 and t,[30] $\%\Delta\ TFP_{US}(H)$ denotes the percent change in the historical total factor productivity for the entire U.S. economy between period t-1 and t, $\%\Delta\ IP_{US}$ denotes the percent change in the historical input prices of all goods and services used to produce output of goods and services in the United States between period t-1 and t, and $\%\Delta\ IP_{LEC}$ denotes the percent change in the historical input prices of local exchange carriers used to produce local service, intrastate toll/access service, and interstate service between period t-1 and t.[31]

J. Kridel *et al., The Effects of Incentive Regulation in the Telecommunications Industry: A Survey*, 9 J. Reg. Econ. 269-306 (1996).

[30] Note that the time period subscripts are suppressed in order to facilitate the exposition.

[31] The basic principle underlying price cap regulation and the need for a X-factor together with relevant literature citations are fully presented in Jeffrey I. Bernstein and David E.M. Sappington, *Setting the X-Factor in Price Cap Regulation Plans*, Working Paper 6622, National Bureau of Economic Research, Cambridge, MA, June 1998.

On the surface, relationship (26) does not appear to be the same as equation (25) which the previous analysis suggests is what is used to calculate the historically justified X-factor. Equation (26) can be rewritten, however, as

(27) $X(H) = \{\%\Delta\ TFP_{LEC}(H)\} + \{-\ \%\Delta\ TFP_{US}(H)) + \%\Delta\ IP_{US}(H) - \%\Delta\ IP_{LEC}(H)\}$.

The term in the first set of brackets in equation (27) corresponds to the variable E_H in equation (25). Therefore, equations (27) and (25) are in fact equivalent if it can be shown that the terms in the second set of bracket of relationship (27) correspond to D_H. This equivalence is demonstrated in what follows. Let RPI(H) denote the rate of change in output prices in the economy as a whole over the historical period. Then, it is always true that

(28) $RPI(H) = -\ \%\Delta\ TFP_{US}(H)) + \%\Delta\ IP_{US}(H)$.

That is, because the economy in aggregate is nearly competitive, the percentage change in output prices is just equal to the percentage change in input prices minus the percentage change in productivity. Substitute relationship (28) into the second bracketed term of relationship (27). Rearranging terms gives

(29) $RPI(H) - \%\Delta\ IP_{LEC}(H)$

This is the historical difference between the rate of change of prices for aggregate output and industry input, which is, by definition, D_H.

(iii) The Use the Residual Value Method for Determining Capital Prices

The above discussion shows that the Commission in the *1997 Price Cap Review Order* implemented price caps and calculated an historically justified X-factor equal to the sum of D_H and E_H where the formulas for estimating D_H and E_H are given by

(30) $D_H = RPI(H) - \%\Delta\ IP_{LEC}(H)$

(31) $E_H = \%\Delta\ TFP_{LEC}(H)$.

This being the case, it is possible to explain the error that the Commission made in the *1997 Price Cap Review Order* in the calculation of the historically justified X-factor.

The 1997 Staff TFP Study associated with the *1997 Price Cap Review Order* made a conceptual error in using actual imputed cost of capital when measuring the productivity of regulated companies. The problem arises because of the use of the residual value approach for determining the cost of the capital input. With this approach, the Commission in the *1997 Price Cap Review Order* first directly determined the price and quantity used of every input (*i.e.*, labor and materials) except capital. That is, it directly calculated the realized return to every non-capital input. Next, based on an estimate of the capital stock, the assumption that all revenue is distributed to the inputs, and given the returns to labor and materials based on historical data, a cost of capital is imputed.

Conceptually, the difference (residual) between revenue and the required returns to all non-capital inputs (which is just the nominal amount used to impute a cost of capital) consists of two parts. The first

part is the required return to capital. The second part is the excess profit earned by the firm. Instead of attempting to separate this difference into two parts, however, the Commission in the *1997 Price Cap Review Order* simply assumed that all of this residual was the required return to capital, *i.e.*, that no excess profit was earned. This is a reasonable assumption for a competitive market, and even for non-competitive markets, as long as the goal of the study is simply to measure the productivity gains revealed by market forces.[32] In a regulatory setting, however, the productivity gains are "revealed" by the application of the X-factor, not by market forces.

By attributing all of the residual to the capital inputs, the residual value method tends automatically to define whatever profits or losses the LECs realized during the historical period as increases or decreases in the cost of capital inputs. Suppose, for example, that the Commission chose too low an X-factor during the historical period being considered, causing the LECs' profits to increase. Under the residual value method, the Commission would conclude that the historical cost of LEC capital inputs rose more rapidly during this period than it actually did. The Commission then would predict an equally large growth in LEC capital cost in the future, and thus calculate an X-factor that was still too low.[33] Consequently, LECs' profits would continue to increase despite no increase in LEC productivity. On the other hand, suppose that the Commission chose too high an X-factor during the historical period, causing LECs' profits to decrease. Under the residual value method, the Commission would conclude that the historical cost of LEC capital inputs fell more rapidly during this period than it actually did. The Commission then would predict an equally large price reduction for capital in the future, and thus calculate an X-factor that was still too high. Consequently, LECs' profits would continue to decrease despite no decrease in LEC productivity. In either scenario, the LECs' productivity remains constant. Only their rate of return is affected by the incorrect X-factor. Thus, the residual value method produces an X-factor that is biased in the same direction as whatever bias existed in the historical period.

To be useful to regulators, then, any X-factor study of a regulated industry must augment or reduce the actual amounts of capital compensation in such a way as to duplicate the forces of a competitive market. Merely replacing the residual capital value method of determining the capital compensation rate with an independent price index would not be sufficient. It would merely cause counterbalancing shifts between the input price differential and the productivity growth rate differential. To capture the gains in productivity that would have been revealed in a competitive market, total capital compensation must vary with the cost of capital one would observe in a competitive market.

In order to correct the miscalculation of the LECs' cost of capital in the 1997 Staff TFP study, it is necessary to replace the TFP study's cost of capital with a competitive cost for the inputs during the historical years. Next, it is necessary to adopt a surrogate to emulate a competitive cost of capital for LECs because LECs have never operated in a competitive market. An independent price series is employed to compute the annual change in the cost of capital for a competitive market.[34] Specifically,

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[32] Dale W. Jorgenson and Zvi Griliches, *The Explanation of Productivity Change*, 34 Rev. Econ. Stud. 249-83 (1967).

[33] One component of the X-factor calculation is the difference between the US Economy's average input costs and the historical input costs of LECs. Thus, an artificially high LEC capital cost will lead to an artificially low X-factor.

[34] Following standard financial economics conventions, the absolute magnitude of the change in the independent price series is used in deference to the relative change. USTA, in its originally proposed method for (continued . . .)

Moody's Baa corporate bond rate reported in the *1999 Economic Report of the President* (Table B-73) is used to calculate the adjustment.[35] These data are reproduced in Table B-8. Combining the base year[36] imputed cost of capital from the 1997 staff TFP study with the change in the competitive cost of capital gives an independent competitive cost of capital for LECs in each year of the historical period. This competitive cost of LECs' capital input is used in conjunction with an adjusted cost of labor (see below) and materials inputs from the 1997 staff TFP study, as well as the percent change in the U.S. nonfarm business sector input price growth, to compute the corrected input price differential portion of the historical X-factor.

Recalculating the LECs' historical cost of capital changes the level of the LECs' revenues, taxes, and operating expenses for the historical years. If the difference between the estimate of the competitive cost of LECs' capital inputs and the imputed cost from the 1997 staff TFP study is computed, an estimate of the excess profits realized by LECs for each year of the historical period is obtained.[37] Reducing the LECs' total revenue by this amount results in a revenue stream that emulates what LECs would have realized in a competitive market. A reduction in revenue implies a reduction in taxes,[38] which in turn reduces total operating expense.[39] It is this reduced total operating expense that is used in the computation of the materials input quantity.

Reducing LEC revenues to what would have been realized in a competitive market also changes the LECs' TFP portion of the X-factor. The new revenue level changes the LECs' input growth rate by altering the relative share of revenue accounted for by each input[40] - labor, materials, and capital.[41] In

computing the cost of capital, uses a proportionate change. See, e.g., Letter from Mary McDermott, Vice President – Legal & Regulatory Affairs, USTA, to William F. Caton, Acting Secretary, FCC, Jan. 20, 1995, Attachment at 11.

[35] Any index for a competitively determined cost of capital should be acceptable because changes in the cost of capital in competitive markets is similar across markets. The use of a different series would yield comparable results given the competitive nature of financial markets. For example, the correlation over the period 1985-1998 between Moody's Aaa corporate bond rate and the Baa rate used is 0.99. Analogously, the correlation between the 10-year U.S. Treasury securities rate and the 30-year U.S. Treasury securities rate and Moody's Baa rate over the same period is 0.99 and 0.98, respectively. In terms of changes in the absolute level of the series, the correlation between Moody's Baa corporate bond rate and Moody's Aaa corporate bond rate, the 10-year U.S. Treasury securities rate, and the 30-year U.S. Treasury securities rate over the period 1985-1998 is 0.99, 0.98, and 0.97, respectively.

[36] The base year is 1991. This is the first full year of LEC price cap. The implicit assumption is that the cost of capital for this year was at a competitive level. That is, it is assumed that LECs earned a normal return in that year.

[37] The LECs' excess profits are due to their output prices falling slower than their cost of capital during the historical years. This situation would not have occurred in a competitive market.

[38] Following standard Commission procedures, it is assumed that taxes are 39 percent (34 percent federal and 5 percent state).

[39] Taxes are one component of operating expenses.

[40] Note that in using shares to aggregate inputs, the 1997 staff TFP study introduced another source of bias. Namely, the observed shares were not cost minimizing shares (*i.e.*, the factors are not paid the value of their marginal products as assumed in the TFP approach). The correction makes an adjustment for this bias.

other words, the LECs' input growth rate changes in response to the changes in the relative weight of each input factor.[42] Combining the output growth rate from the 1997 staff TFP study with the revised LECs' input growth rate yields the corrected TFP growth rate for the LECs.

(e) Materials - Part II

As noted, an adjustment to the cost of capital changes the effective total operating expense due to a change in taxes. The adjusted total operating expense less labor compensation less depreciation and amortization divided by the materials price index gives materials input quantity. The materials price index is the same as that used in the *1997 Price Cap Review Order*.[43] The materials input quantity series is found in Table B-9.

(f) Total Input Quantity Index

Having constructed input quantity indexes for each of the factors of production, a composite input index can be computed. Using relative shares of payments to each of the factors as weights, an aggregate input value for each year is calculated. These values are used to compute a Fisher Ideal Index for input quantity.

To compute the relative shares, payments to each of the factors is needed. The payment to labor is adjusted total compensation, the payment to materials is adjusted materials expense, and the payment to capital is adjusted property income with depreciation. Adjusted property income is capital stock quantity in period t-1 times the imputed competitive cost of capital for period t. Adjustments to material payments and property income (capital compensation) have been previously discussed. Adjustments to labor compensation are deferred to a subsequent section. Payments to the factors of production together with factor shares are given in Table B-10.

The composite Fisher Ideal Input Quantity Index is derived by chaining the Fisher Ideal Input Quantity Index. The resulting Fisher Ideal Chained Input Quantity Index is given in Table B-11. Note that the percentage changes (growth rate) are calculated as natural logarithmic ($\log_e$) changes.

Total Factor Productivity for LECs and the TFP Differential

The percentage change in total factor productivity is the measure for the productivity component of the X-factor. This is calculated as the percentage change in total output (Table B-4) less the percentage

[41] The recalculation does not change the labor and capital input quantity indexes. The materials input index, however, (computed as the total operating expenses minus labor compensation, depreciation, and amortization), changes when the operating expenses are reduced.

[42] The change in relative weights means that the weights used in computing the LECs' input price growth must be recomputed which, in turn, implies a recomputation of LECs' excess profits, etc. This is an iterative process.

[43] The price index is based on those categories of expenditures from the National Input-Output Tables compiled by the Bureau of Economic Analysis of the U.S. Department of Commerce that focus on materials purchases by communications industries. The materials price index is a Tornquist index.

change in input quantity (Table B-11). For both output and input quantity, the Fisher Ideal Chained Index is used. The percentage changes (growth rate) are calculated as natural logarithmic ($\log_e$) changes. Annual changes together with the historical averages for various periods is given in Table B-10.

The productivity component of the X-factor as specified in relationship (26) consists of the difference between LECs TFP growth rate and the TFP growth rate of the aggregate economy. This differential is presented in Table B-12. The Bureau of Labor Statistics of the U.S. Department of Labor estimate of Private Nonfarm Business Sector Multifactor Productivity is used to compute the TFP growth rate for the aggregate economy.[44,45] The 1998 value of this multifactor productivity series is not currently available. It is forecast by estimating a structural relationship between output per hours of all persons employed and private nonfarm business multifactor productivity using a double logarithmic ($\log_e$) transformation. Data for output per hour of all persons employed for 1998 is available from the Bureau of Labor Statistics[46] and is used to generate the forecast.[47]

The results indicate that total factor productivity of LECs grew about 4.2 percent faster than productivity in the nonfarm private business sector of the economy over the 1986 to 1998 period.

Calculation of Input Price Indexes

The second component of the X-factor is the input price differential. This is just the value in the second set of parentheses in equation (26), $\%\Delta\ IP_{US}(H) - \%\Delta\ IP_{LEC}(H)$. Focus for now on the changes in LEC input prices. The price of each factor of production will be considered separately.

(a) Labor

Total labor compensation divided by the number of employees gives a simple way of computing the average annual price of labor. The resulting series, however, is not homogeneous over the 1985-1998 period and hence it introduces measurement error into the analysis. Between 1985 and 1998, the price of labor, defined as the average compensation per employee,[48] increased in real terms at a 3.6 percent annual

[44] The multifactor productivity series is revised from that used in the *1997 Price Cap Review Order*. After decades of research and constructive advocacy by Jorgenson (Dale W. Jorgenson, *Productivity and Economic Growth, in* Fifty Years of Economic Measurement: The Jubilee of the Conference on Research in Income and Wealth (Ernst R. Berndt and Jack E. Triplett eds. 1990)), the Bureau of Labor Statistics of the U.S. Department of Labor in 1994 adopted the Jorgenson framework for composition adjustment for all of its publications on multifactor productivity growth over the period since 1948.

[45] The annual series is from Table 2: Private Nonfarm Business: Productivity and Related Indexes, 1948-97. It is available via the Bureau of Labor Statistics Internet site at http://www.bls.gov.

[46] It is available from the same Bureau of Labor Statistics site as the multifactor productivity series.

[47] The coefficient of determination is 0.88. It is necessary to correct for first order serial correlation. Also, regression diagnostics indicated that the multifactor productivity datum for 1991 is an outlier. To correct for this, the specification includes a dummy variable for this year.

[48] The average compensation per employee is equal to total labor compensation divided by the number of employees.

rate. In terms of total compensation, the amount paid for labor was approximately the same in 1985 as it was in 1998 even though the number of workers in the aggregate had been reduced by over 30 percent. The reason for this, at least in part, is that, coincident with the adoption of price cap plans, labor force reductions were accomplished by offering employees monetary incentives to leave the company (*i.e.*, buyouts). There is some variability in the applicable accounting rules,[49] but these payments were generally accrued as one-time charges against current earnings.[50,51]

To have a labor price series meaningful for TFP analysis, it is necessary to adjust for the impact of the exogenous changes in labor compensation and accounting rules. This is accomplished by adjusting the labor compensation series to net out one-time charges for such things as buyouts and accounting rule changes. Sufficiently detailed information to allow for such an adjustment to the total compensation series is not available from *Statistics of Communication Common Carriers*, the source of the total labor compensation and number of employees data used in the *1997 Price Cap Review Order*. Alternate data must be relied upon. These data are discussed below.

From the FCCs' ARMIS Report 43-02, total compensation for the year is defined to equal payroll, including salaries, wages, and payroll related benefits. Separate items from the same report include salaries and wages and benefits. Salaries and wages are defined to equal salaries, wages, commissions, bonuses, incentive awards, and termination payments. Benefits include pensions, saving plan contributions, worker's compensation, life and health insurance, social security and other payroll taxes. These data series are reported in Table B-5.[52] Benefits are equal to approximately 20 percent of the sum of salaries plus wages plus benefits for the years 1988-1990. Subsequently, they increase annually, reaching a maximum of 30 percent in 1994 and then decline to approximately 21 percent in 1998. The increase in the proportion of benefits above 20 percent is assumed to be the amount attributed to buyouts, accounting rule changes, and so on. This amount is nominally referred to as excess benefits. This is the amount that must be netted out to give a labor compensation series that can be used in the TFP analysis.

Using this rule, excess benefits are computed with the resulting amount subtracted from total compensation to give the adjusted labor compensation series in Table B-5.[53] The values in this series divided by the number of workers gives an adjusted labor price. The adjusted labor price index is then computed (Table B-5).

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[49] See, e.g., Financial Accounting Standards Board Rule (FASB) Number 106.

[50] Donald J. Kridel *et al.*, *The Effects of Incentive Regulation in the Telecommunications Industry: A Survey*, 9 J. Reg. Econ. 269-306 (1996).

[51] The cost of labor input (management and non-management) in the *1997 Price Cap Review Order* is equal to wages and salaries expenses plus benefits expenses. This suggests that the lump-sum incentive payments would be recorded as labor costs. A key issue is a measurement problem since accounting data do not reflect the real cost accurately. To the extent that direct observations on labor input (*i.e.*, actual hours worked) are used, however, any disparities between accounting costs and real costs could be avoided. Unfortunately, labor input is not measured by the number of hours worked but as the total number of employees.

[52] The data series for ARMIS salaries and wages and benefits are incomplete prior to 1988 due to reporting changes and hence not used. The requisite adjustments would be *ad hoc* and introduce further measurement error into the analysis.

[53] With the adjustment in labor compensation comes an adjustment in total operating expenses.

(b) Capital

As noted previously, in order to correct the miscalculation of the LECs' cost of capital in the 1997 Staff TFP study, it is necessary to replace the TFP study's cost of capital with a competitive cost for the inputs during the historical years. Next, it is necessary to adopt a surrogate to emulate a competitive cost of capital for LECs because LECs have never operated in a competitive market. An independent price series is employed to compute the annual change in the cost of capital for a competitive market. Specifically, Moody's Baa corporate bond rate reported in the *1999 Economic Report of the President* (Table B-73) is used to calculate the adjustment. Combining the base year imputed cost of capital from the 1997 staff TFP study with the change in the competitive cost of capital gives an independent competitive cost of capital for LECs in each year of the historical period.

(c) Materials

The materials price index is the same as that used in the *1997 Price Cap Review Order*. The price index is based on those categories of expenditures from the National Input-Output Tables compiled by the Bureau of Economic Analysis of the U.S. Department of Commerce that focus on materials purchases by communications industries. The materials price index is a Tornquist index. The materials price index is given in Table B-9.

(d) Total Input Price Index

Having constructed input price indexes for each of the factors of production, a composite input index can be computed. Using relative shares of payments to each of the factors as weights, an aggregate input value for each year is calculated. These values are used to compute a Fisher Ideal Index for input price.

To compute the relative shares, payments to each of the factors is needed. The payment to labor is adjusted total compensation, the payment to materials is adjusted materials expense, and the payment to capital is adjusted property income with depreciation. Adjusted property income is capital stock quantity in period t-1 times the imputed competitive cost of capital for period t. Adjustments to material payments and property income (capital compensation) have been previously discussed. Adjustments to labor compensation are deferred to a subsequent section. Payments to the factors of production together with factor shares are given in Table B-10.

The composite Fisher Ideal Input Price Index is derived by chaining the Fisher Ideal Input Price Index. The resulting Fisher Ideal Chained Input Price Index is given in Table B-13. Note that the percentage changes (growth rate) are calculated as natural logarithmic ($\log_e$) changes.

Input Price Differential

The input price differential, the second component of the X-factor, is computed as the percentage change in input prices for the aggregate economy less the percentage change in LECs' input prices. The

measure of aggregate input price change used is the Nonfarm Business Sector Input Price Index compiled by the Bureau of Labor Statistics of the U.S. Department of Labor.[54]

The input price differential is presented in Table B-12. The results suggest that input prices in the nonfarm private business sector of the economy grew about 1.8 percent faster than input prices for LECs' over the 1986 to 1998 period.

The X-Factor

The computed X-factor defined by equation (26) and consisting of a productivity component plus an input price differential component is presented in Table B-12. Averages for different time period intervals are presented. The average is in the range of 5.8 to 6.3 percent. It is interesting to note that the averages are approximately equal for these different time periods.[55]

[54] The series is quarterly and is taken from Table 2: Private Nonfarm Business: Productivity and Related Indexes, 1948-97. It is available via the Bureau of Labor Statistics Internet site at http://www.bls.gov.

[55] The mean values used in conjunction with their respective variances and sample sizes indicate that, in fact, there is no statistically significant difference at the 5 percent level.