UNITED STATES
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**ex parte**

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March 28,1997

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Federal Communications Commission
Office of Secretary

Mr. William F. Caton
Secretary
Federal Communications Commission
1919 M Street, NW, Room 222
Washington, D.C. 20554

Re: Ex Parte
CC Docket No.96-262

Dear Mr. Caton:

On Friday, March 28, 1997, the attached document was sent to Anthony Bush of the FCC Staff. This material is the direct testimony of Laurits R. Christensen in North Dakota on October 1, 1990 for U.S. West regarding an analysis of a productivity study filed in that state proceeding. USTA has relied upon the underlying support materials from this analysis in its development of a total factor productivity studies filed in this proceeding and in CC Docket 94-1, Fourth Further Notice of Proposed Rulemaking.

The original and a copy of this letter and attachment, at the request of Dr. Bush of the Commission staff, are being filed in the office of the Secretary today. Please include this material in the record of the above reference proceeding.

Respectfully submitted,

Frank McKennedy
Director - Legal and Regulatory Affairs

cc with attach: Dr. Anthony Bush

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NORTH DAKOTA PUBLIC SERVICE COMMISSION
Case No. PU-2320-90-149

U S WEST COMMUNICATIONS

DIRECT TESTIMONY

OF

LAURITS R. CHRISTENSEN

OCTOBER 1, 1990

1 Case No. PU-2320-90-149

2 Direct Testimony of Laurits R. Christensen

3 Q. What is your name and address?

4 A. My name is Laurits R. Christensen, and I reside at 1711 Kendall
5 Avenue in Madison, Wisconsin.

6 Q. What is your educational background?

7 A. I studied engineering and economics at Cornell University, from
8 which I graduated in 1964. I did my graduate work at the University
9 of California, Berkeley, where I obtained an M.S. in statistics and a
10 Ph.D. in economics.

11 Q. How have you been employed as a professional economist?

12 A. From 1967 to 1987 I was Professor of Economics at the University
13 of Wisconsin-Madison. Since 1976 I have also been president of
14 Christensen Associates, a private firm located in Madison that
15 performs economic studies for government and private clients.
16 Serving as President of Christensen Associates is now my full-time
17 occupation. Full details of my employment experience are contained
18 in my resume, which is Schedule 1 of my Exhibit.

19 Q. Do you have experience in the analysis of productivity?

20 A. Yes. I have specialized in productivity analysis ever since my
21 graduate studies in the mid-1960's, and I have published numerous
22 papers on this subject. These papers include methodological
23 developments, as well as actual measurement of productivity
24 performance for individual firms and industries, and for the entire
25 economies of various countries. A complete listing of these papers

1 is contained in Schedule 1 of my Exhibit.

2 Q. Do you have experience in the analysis of productivity for
3 telephone companies?

4 A. Yes. In the late 1970's I performed extensive productivity
5 analysis for AT&T and the Bell System. During the 1980's I studied
6 productivity issues for AT&T and various local exchange companies.

7 Q. Do you have experience in the development of economic indexes
8 other than productivity?

9 A. Yes. I have published numerous papers regarding economic
10 indexes. I have also been employed as a consultant by the U.S.
11 Bureau of Labor Statistics on matters involving the construction of
12 economic indexes.

13 Q. What is the purpose of your testimony?

14 A. I have been asked by U S WEST to analyze and discuss the issues
15 related to the calculation of the Input Cost Index and the
16 Productivity Incentive Adjustment.

17 Q. Do you agree with the rationale proposed by Dr. Dobesh and
18 accepted by the Commission that the Input Cost Index (ICI) should be
19 a broad-based measure of inflation in the U.S. economy?

20 A. Yes, I do.

21 Q. Is the Gross National Product Price Index (GNPPI) an appropriate
22 broad-based measure of inflation in the U.S. economy?

23 A. Yes, it is, provided that it is recognized that the GNPPI is a
24 measure of <u>output</u> price inflation rather than <u>input</u> price inflation.
25 Output price inflation is lower than input price inflation--the

1 difference between them is the rate of growth of total productivity;
2 so the GNPPI cannot be used to reflect input price inflation without
3 taking into account the amount of total productivity growth in the
4 U.S. economy.

5 Q. Did Dr. Dobesh and the Commission recognize that the GNPPI is a
6 measure of output price inflation?

7 A. Yes, they did. They recognized that it is appropriate to use
8 the GNPPI (a measure of output price inflation) to represent the
9 Input Cost Index (input price inflation) only if the Productivity
10 Incentive Adjustment is based on the difference between U S WEST's
11 expected productivity growth and the expected productivity growth of
12 the U.S. economy.

13 Q. What concept of productivity is appropriate for measurement of
14 the Productivity Incentive Adjustment?

15 A. Total productivity (sometimes called total factor productivity)
16 is the appropriate concept. Total productivity indicates the ratio
17 of all outputs to all inputs. Partial measures of productivity, such
18 as "labor productivity" are not appropriate because they do not
19 include all inputs. They include only a subset of the total input of
20 resources.

21 Q. Is your belief that total productivity is the relevant concept
22 consistent with the North Dakota statute?

23 A. Yes. N.D.C.C. 49-21-01(9) defines "productivity" as "a measure
24 of a telecommunications company's total output of services and
25 products to the total amount of input of resources used to produce

1 those services and products". This definition establishes
2 unambiguously that the North Dakota legislature intended the
3 Productivity Incentive Adjustment to be based on total productivity.
4 Q. Have there been any studies of the growth of total productivity
5 in the U.S. telecommunications industry?
6 A. Yes, there have. The most in-depth study is one that I
7 performed for AT&T and the Bell System, which measured total
8 productivity growth from 1947 through 1979. In that study I
9 distinguished 110 categories of labor input, 21 categories of capital
10 input, 6 categories of "materials" input, and 5 categories of
11 output. ("Materials" refers to all goods and services purchased by a
12 firm other than capital goods and labor services. This category is
13 sometimes called "intermediate" input.) These categories of output
14 and input were combined to obtain annual figures for total
15 productivity growth. My study, which was co-authored with Dianne
16 Cummings Christensen and Philip E. Schoech, is provided as Schedule 2
17 of my Exhibit.
18 Q. Has your study been updated beyond 1979?
19 A. No, it has not.
20 Q. Can your study be updated using publicly-available data sources?
21 A. No, it is not feasible to update the study because of data
22 limitations. But it is feasible to obtain a good approximation to
23 the results of my in-depth study by using a few publicly-available
24 data sources.
25 Q. Have you done so?

1 A. Yes. In fact, I have computed productivity growth for the U.S.
2 telecommunications industry for 1951 through 1987. Data limitations
3 make it difficult to go back before 1951, and 1987 is the most recent
4 year for which all the relevant data are available. My current study
5 of total productivity growth in the U.S. telecommunications industry
6 is provided in Schedule 3 of my Exhibit.
7 Q. What has been the rate of growth of total productivity for the
8 U.S. telecommunications industry?
9 A. Over the entire period from 1951 through 1987, total
10 productivity has grown at an average annual rate of 3.1%, a rate that
11 is very similar to the 3.2% average annual rate for 1951-1979 found
12 in my previous study.
13 Q. If you were to limit your current study to 1951-1979, would the
14 results correspond to those in your previous study?
15 A. Yes, there is a close correspondence. The two studies overlap
16 for 28 years--1951 through 1979--and the results of the two studies
17 correspond closely for those 28 years. For 1951 through 1979, my
18 previous study found that total productivity growth averaged 3.2% per
19 year, and my current study indicates total productivity growth of
20 3.6% per year over the same time period. Thus the data and methods
21 that I am currently using probably overstate the actual rate of total
22 productivity growth, but the overstatement is relatively small.
23 Therefore, I conclude that my current study, which is easy to
24 replicate, provides a valid measure of total productivity growth for
25 the U.S. telecommunications industry. The measure may overstate, but

1 is unlikely to understate, the actual historical rate of total
2 productivity growth.
3 Q. What has been the growth in telecommunications productivity
4 since 1979?
5 A. My analysis indicates that from 1979 through 1987 the average
6 annual rate of growth of total productivity for the U.S.
7 telecommunications industry was 1.6%, which is substantially less
8 than the rate from 1951 through 1979.
9 Q. Does this indicate that there has been a decline in the
10 long-term rate of total productivity growth for U.S.
11 telecommunications?
12 A. There was a substantial slowdown in total productivity growth in
13 the 1980's. But it is not yet clear whether this slowdown was
14 temporary, or whether it will continue indefinitely.
15 Q. Some observers claim that recent and prospective technical
16 developments portend an acceleration of productivity growth in the
17 U.S. telecommunications industry relative to the U.S. economy. Is
18 there any evidence to support this claim?
19 A. No, none that I know of. For the past 40 years there has been
20 more rapid technical change in the telecommunications industry than
21 in other industries, and this has been manifested (until the last few
22 years) in a higher rate of total productivity growth for
23 telecommunications than for the rest of the economy. But I know of
24 no evidence to support a belief that in the near future total
25 productivity growth for telecommunications will surpass total

1 productivity growth for the entire U.S. economy by more than it has
2 in the past. In fact, as I will discuss later in my testimony, the
3 converse has been true for the 1980's.
4 Q. Won't the current changes in technology increase total
5 productivity growth in the telecommunications industry for the
6 indefinite future?
7 A. No. Any improvement in technology can raise total productivity
8 to a higher level, which can be maintained indefinitely. But such an
9 improvement in technology will enhance the growth of total
10 productivity only temporarily. In order for the growth of total
11 productivity in telecommunications to remain indefinitely above the
12 growth in total productivity for the economy, it would be necessary
13 to have improvements in telecommunications technology that
14 continually widened the gap between the level of total productivity
15 for telecommunications and the level of total productivity for the
16 rest of the economy.
17 Q. Does the Federal Communications Commission (FCC) have a position
18 on this question?
19 A. Yes, the FCC's position is the same as mine. In CC Docket
20 No. 87-313, Supplemental Notice of Proposed Rulemaking (released
21 March 12, 1990), Paragraph No. 107 states: "Moreover, we do not
22 agree with parties that contend that the Commission has overlooked
23 significant potential productivity gains that will be realized
24 through technological innovation in selecting its productivity factor
25 . . . no data have been presented that refute the well-established

1 fact that the communications industry, since its inception, has been
2 marked by technological innovation. This being the case, our
3 productivity factor, based on the long-run historical experience of
4 the industry, already reflects this characteristic."
5 Q. In the Findings of Fact, Conclusions of Law and Order for Case
6 No. PU-2320-89-333, the North Dakota Commission used figures on labor
7 productivity published by the U.S. Bureau of Labor Statistics to
8 ". . . reflect historical industry productivity . . . ". Is it
9 appropriate to use labor productivity growth as a proxy for total
10 productivity growth?
11 A. No. In general, labor productivity growth is an unacceptable
12 proxy for total productivity growth. It would be an acceptable proxy
13 only if labor input for a company or industry were to grow at
14 approximately the same rate as capital and materials input. But for
15 most companies and industries, labor input grows more slowly than
16 capital and materials inputs. The result is that labor productivity
17 growth generally provides an estimate of total productivity growth
18 that is erroneously high.
19 Q. In the telecommunications industry, is labor productivity growth
20 an acceptable proxy for total productivity growth?
21 A. No. Throughout the post World War II period, labor productivity
22 growth for the telecommunications industry has greatly overstated the
23 growth of total productivity. For example, my study of productivity
24 growth for AT&T and the Bell System showed that from 1947 to 1979
25 total productivity grew 3.2% per year. During the same period labor

1 productivity growth averaged 5.6% per year; so for this period labor
2 productivity growth would have been an unacceptable proxy for total
3 productivity growth--overstating total productivity growth by 75%.
4 Q. The BLS publishes two series on labor productivity, output per
5 employee and output per hour worked; is there any basis for
6 preferring one of these two measures?
7 A. Neither provides a good proxy for total productivity, but output
8 per employee hour is clearly a better measure of labor productivity
9 than output per employee. Measuring labor input by the number of
10 employees fails to capture changes in the proportion of part-time
11 workers, who contribute less labor input than full-time workers. A
12 simple count of employees also fails to capture changes over time in
13 the number of hours worked per week by full-time employees.
14 Therefore, output per employee hour is a preferable measure of labor
15 productivity, but it is still an unacceptable proxy for total
16 productivity.
17 Q. Do you think it is appropriate to use (as the Commission has)
18 nationwide figures to represent the expected productivity growth for
19 U S WEST?
20 A. Yes, I do. U S WEST has opportunities to increase its total
21 productivity that are similar to the opportunities faced by other
22 telecommunications companies in the United States. In particular,
23 U S WEST has access to the same technology and the same sources of
24 inputs as other telecommunications companies.
25 Q. Do you have any concern that nationwide figures might overstate

1 the productivity growth opportunities for U S WEST in North Dakota?

2 A. I have some concern because the population of North Dakota is

3 growing more slowly than the average for all states.

4 Q. How is population growth relevant to total productivity growth?

5 A. Total productivity growth is generally correlated with growth in

6 the density of service, and density of service tends to grow in

7 proportion to the total population of a state.

8 Q. What do you believe to be the best available estimate of

9 expected total productivity growth for U S WEST in 1991, relative to

10 the U.S. economy?

11 A. My concern over density notwithstanding, I believe the recent

12 trend of total productivity growth for the U.S. telecommunications

13 industry relative to the U.S. economy provides the best available

14 estimate. As I discuss at length below, I have found this number to

15 be 1.9%.

16 Q. What do you mean by recent trend?

17 A. By "recent trend" I mean the average rate of growth over a

18 sufficient number of years to smooth out the effects of business

19 cycles and other special circumstances--but not so long as to give a

20 very small weight to the experience of the most recent years.

21 Q. What period did the North Dakota Commission use to determine the

22 historical pattern of productivity growth for U.S. telecommunications?

23 A. It used the 1975-1987 period.

24 Q. Does this period satisfy your definition of "recent trend"?

25 A. Yes, it does.

1 Q. Do you accept, then, the Commission's determination of the
2 historical productivity trend?
3 A. No, I do not. The Commission's determination was based on
4 historical growth in labor productivity rather than historical growth
5 in total productivity. But, as I stated earlier, total productivity
6 is the appropriate concept; labor productivity cannot be relied upon
7 to serve as a valid proxy for total productivity. In addition to
8 being dictated by economic logic, the use of total productivity
9 growth rather than labor productivity growth is dictated by the North
10 Dakota statute. Moreover, to my knowledge, no one has claimed that
11 labor productivity has any relevance to the Productivity Incentive
12 Adjustment. In fact, the Commission's own consultant and witness,
13 Dr. Dobesh, has testified that the relevant concept is total
14 productivity growth rather than labor productivity growth.
15 Q. What has been the rate of growth of total productivity for the
16 telecommunications industry relative to the U.S. economy for the
17 1975-1987 period?
18 A. My computations in Schedule 3 indicate total productivity growth
19 for the U.S. telecommunications industry of 2.7% per year from 1975
20 to 1987. Schedule 3 also indicates total productivity growth of 0.8%
21 per year for the U.S. economy for the same period. The difference
22 between 2.7% and 0.8%, which equals 1.9%, reflects the average annual
23 rate of total productivity growth in telecommunications relative to
24 the U.S. economy.
25 Q. Why do you subtract total productivity growth in the U.S.

1 economy from total productivity growth in the U.S. telecommunications
2 industry?
3 A. As I explained earlier in this testimony, it is necessary
4 because the GNPPI, an index of output prices, is being used as the
5 Input Cost Index.
6 Q. How does this differ from the labor productivity proxy used by
7 the Commission in its Order?
8 A. The Commission used two different labor productivity figures
9 from the BLS for the 1975-87 period. The differences between the BLS
10 labor productivity growth rates for telecommunications and the
11 corresponding rates for the U.S. economy were 4.0% and 5.5%,
12 respectively. The Commission averaged these two figures to obtain
13 4.75%, which it stated was reflective of the productivity growth
14 differential for U.S. telecommunications and the U.S. economy. My
15 study shows that 4.75% is far higher than the actual figure of 1.9%
16 for the 1975-1987 period.
17 Q. Has anyone besides you investigated the historical relationship
18 between total productivity growth in the U.S. telecommunications
19 industry and the U.S. economy?
20 A. Yes, in CC Docket No. 87-313, which has been in progress since
21 1987, the Federal Communications Commission has made such an
22 investigation.
23 Q. What has the FCC found?
24 A. In the most recent (released March 12, 1990) notice of
25 rulemaking issued in CC Docket No. 87-313, the FCC has summarized its

1 lengthy deliberations on the productivity issue. Paragraphs 23 and
2 24 state: "The Commission has reviewed evidence on LEC productivity
3 on two occasions. In the Further Notice the analysis of productivity
4 data led the Commission to conclude that the best estimate of
5 potential annual productivity gain in the telecommunications industry
6 as a whole is 2.5 percent over and above the level achieved by the
7 economy. . . . In the Second Further Notice, the Commission
8 reaffirmed its tentative view that 2.5 percent is the best estimate
9 of the differential between LEC productivity and the productivity of
10 the economy as a whole. The Second Further Notice also restated the
11 Commission's tentative view that LEC productivity is not likely to
12 vary from the long-term trend on a sustained basis due to technology
13 now in use, the installation of new technology, investment patterns,
14 or other characteristics."
15 Paragraph 91 further states: "We remain confident that
16 2.5 percent is the most reasonable estimate of the historical
17 productivity offset." And finally, Paragraph 106 states: ". . . the
18 Commission's tentative selection of a 2.5 percent productivity offset
19 was not a hastily made decision or a decision that was made without
20 documented support. Indeed, as the record exhaustively details, the
21 Commission carefully considered various means of measuring
22 productivity and only after examining them closely, with full
23 participation from interested parties, was the proposed offset
24 selected from available evidence." [5 FCC Rcd 2176 (1990)]
25 Q. Has the FCC found any difference in the productivity growth

1 trends for the LECs (local exchange carriers) and the entire
2 telecommunications industry?
3 A. No. To date the FCC has found no basis for using a different
4 productivity growth trend for the LECs.
5 Q. How do you reconcile your finding of a 1.9% productivity
6 differential with the FCC's finding of a 2.5% differential?
7 A. The 1.9% differential reflects the most recent 12-year period
8 for which data are available, including the slowdown in the 1980's.
9 The 2.5% is reflective of the long-term trend and gives little, if
10 any, weight to the slowdown in the 1980's. In fact, the FCC gave
11 extra weight to the 1970's, which was a period of extraordinarily
12 good productivity growth for the U.S. telecommunications industry.
13 (See Table 3-9 of my Schedule 3.)
14 Q. Suppose you were to limit yourself to the 1980's to determine
15 the trend of the total productivity growth differential. How would
16 your findings differ?
17 A. Limiting consideration to total productivity growth in the
18 1980's would imply using 1979 as the base year, rather than 1975.
19 For the 1979 to 1987 period, the total productivity growth
20 differential was 1.0% per year, rather than 1.9%. (See Schedule 3.)
21 Q. Suppose you were to limit yourself to the period since
22 divestiture (January of 1984) to determine the productivity growth
23 differential. How would your findings differ?
24 A. Limiting consideration to total productivity growth since
25 divestiture would imply using 1983 as the base year. For the 1983 to

1987 period, the total productivity growth differential was -.3% per year, rather than 1.9%. (See Schedule 3.) That is, rather than the historical situation of telecommunications total productivity growth exceeding total productivity growth for the entire economy, the converse has been true since divestiture.

Q. What figure do you recommend for the 1991 PIA for U S WEST?

A. I recommend .019.

Q. If the North Dakota Commission were to use the same procedure to compute the 1991 ICI as it used to compute the 1990 ICI, what would the 1991 ICI be?

A. It would be 1.0428, as I show in Schedule 4 of my Exhibit.

Q. Using the Commission's approach to measuring the ICI and your recommended figure for the PIA, what would be the 1991 ETPF for U S WEST?

A. Using the formula ETPF = ICI - (50% PIA) yields 1.0428 - (50% x .0190) = 1.0333.

Q. Would it be appropriate to fix the PIA for several years, as recommended by Dr. Dobesh, in the computation of the ETPF?

A. Yes, it would. The trend in productivity growth for telecommunications relative to the U.S. economy is not likely to change dramatically in the next few years.

Q. If the Commission preferred to establish a formula that could be used to set the PIA each year, would that be feasible?

A. Yes, it would. In Schedule 5 of my Exhibit I have specified the data series and a formula that could be used to update the PIA each

1 year.

2 Q. Mr. Christensen, does this conclude your testimony?

3 A. Yes, it does.

Economic Analysis and Consulting

# TOTAL FACTOR PRODUCTIVITY IN THE BELL SYSTEM 1947-1979

by

Laurits R. Christensen
Dianne Cummings Christensen
Philip E. Schoech

September 1981

Table of Contents


| | | Page |
|---|---|---|
| 1. | Introduction | 1 |
| 2. | Methodology | 2 |
| 3. | Measurement of Output | 10 |
| 4. | Measurement of Labor Input | 17 |
| 5. | Measurement of Capital Input | 24 |
| 6. | Measurement of Materials Input | 50 |
| 7. | Total Factor Productivity | 53 |

# 1. INTRODUCTION

The purpose of this paper is to provide an intertemporal comparison of total factor productivity (TFP) for the Bell System in the production of telecommunications services.[1] TFP indicates the overall level of efficiency that is achieved by a firm in transforming resources (labor, capital, and materials) into goods and services.[2] We use the index number approach to estimate the year-by-year rate of change in TFP by the Bell System over the period 1947-79.

The measurement of TFP requires a detailed set of accounts, separating the value of each input and output into its quantity and price components. In Section 2 we describe the index number procedures employed to separate output and factor input in current prices into price and quantity components. We also define TFP in terms of these index numbers and specify measures of real labor, capital, and materials inputs and measures that reflect changes in the composition of labor and capital. In Sections 3, 4, 5, and 6, we present the data and procedures used to construct input and output quantities and prices. In Section 7 we show the resulting total input, total output and TFP indexes.

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[1]For this study we define the Bell System to include AT&T Co., AT&T Long Lines, and all Bell Operating companies in which AT&T Co. has controlling interest.

[2]Fabricant (1974) provides an overview of productivity measurement.

## 2. METHODOLOGY

2.1 Introduction. In this section we present our methodology for constructing an index of TFP. The conventional approach to the measurement of TFP involves the computation of an index of real output and an index of real factor input. TFP is defined as the ratio of the real output to real factor input. Alternative approaches differ substantially in the choice of procedures for obtaining indexes of aggregate output and input.

2.2. Theory of Index Numbers. The traditional method for aggregating individual outputs and inputs is to use the Laspeyres index. The Laspeyres index can be written as

$$X_1/X_0 = \Sigma\ p_{i0}X_{i1}/\Sigma\ p_{i0}X_{i0} = \Sigma w_{i0}(X_{i1}/X_{i0}) \tag{1}$$

where $w_{i0} = p_{i0}X_{i0}/\Sigma\ p_{i0}X_{i0}$, the subscript zero is the base period, and the subscript one is the comparison period. The widespread use of the Laspeyres index evidently stems from its ease of use and intuitively appealing interpretation. Since prices are being held fixed at their base period levels, the Laspeyres index purports to show how much of the change in value of total input results from changes in quantity.

An alternative approach widely used in current empirical research is the (arithmetic average) weighted log-change index

$$\ln\ (X_1/X_0) = \Sigma\ \bar{w}_i\ \ln\ (X_{i1}/X_{i0}) \tag{2}$$

where $\bar{w} = (w_{i1} + w_{i0})/2$. This index is one of many mentioned in passing by Fisher (1922). It has been recommended for applications by Tornqvist (1936) and

subsequently by Theil (1965) and Kloek (1966). It has been used by Christensen and Jorgenson (1969, 1970, 1973a, 1973b) to implement a complete system of national accounts in current and constant prices. In this paper we refer to this index number procedure as the Tornqvist index. A convenient feature of the Tornqvist index is that for time series data the log-changes can be interpreted as rates of growth, since:

$$\dot{X}/X = d \ln X/d t \quad = \Delta \ln X_t = \ln (X_t/X_{t-1})$$

The economic theory of exact index numbers can be described as rationalizing index number formulas by particular functional forms for production functions. Recent contributions to this theory have been made by Afriat (1972), Diewert (1976), Pollak (1971) and Samuelson and Swamy (1974). Index number formulas have long been thought of as approximating production functions. Results are now available showing that index number formulas represent exactly particular production functions. The production functions underlying both the Laspeyres Index and the Tornqvist Index have been discovered.

The Laspeyres Index is exact for a linear production function, which specifies a priori that all factors are perfect substitutes in the production process. The Tornqvist Index is exact for the homogeneous translog production function proposed by Christensen, Jorgenson, and Lau (1971, 1973). The homogeneous translog production function can provide a second order approximation to an arbitrary twice-differentiable homogeneous production function. Diewert (1976) has used the term "superlative" to characterize index numbers which are exact for production functions having this approximation feature. Such production functions are often referred to as "flexible" because they can approximate production structures with arbitrary substitution possibilites.

A fundamental result of the economic theory of production is that producers minimize costs of production by using all inputs in proportions such that their marginal productivities are equal to their purchase prices. The indexes we have been discussing can be interpreted as using prices or marginal productivities to weight input quantities. The basic difference between the Laspeyres and the Tornqvist (and other superlative) Indexes is that the Laspeyres Index holds prices fixed at their base period levels while the Tornqvist Index uses the prices from both the base period and the comparison period.

The use of fixed base period prices in the Laspeyres Index can be interpreted in terms of the linear production function. If there is perfect substitutibility among factors of production, then an increase in the relative price of any one input would cause discontinuation of its use. If a perfect substitute is available at a lower price, there is no rationale for using the higher priced input. If all inputs are used in both the base period and the comparison period, it follows that the relative prices are the same in both periods. There is no need to consider the comparison period prices since they are unchanged from the base period.

The translog function does not require inputs to be perfect substitutes. If the relative price of an input increases, the producer decreases its use (substituting other inputs) until all marginal productivities are proportional to the new prices. Hence, the prices from both periods enter the Tornqvist Index to represent the marginal productivities in both periods. Diewert (1976) has also discussed other members of the class of superlative indexes. This class includes the geometric mean of the Laspeyres and Paasche indexes. This procedure was advocated by Fisher (1922), and has since been known as the Fisher Ideal index.

Ruggles (1967) used data from 19 Latin American countries to compare the results of using several indexes including the Laspeyres, Paasche, Fisher Ideal and Tornqvist

indexes. He found that the Laspeyres and Paasche indexes differed radically from each other and substantially from the Tornqvist and Fisher Ideal indexes. However, the Tornqvist and Fisher Ideal indexes were virtually identical. This provides evidence that it can be important to use a superlative index but that the choice among superlative indexes is of much less importance. Following Christensen and Jorgenson (1973a), we adopt the Tornqvist index for all results reported below.

2.3. Real output and real factor input. Total factor productivity uses an index of real product. Denoting the index by Y, we express the fuctional relationship between aggregate output and its components as

$$Y = f_y(Y_1, Y_2, \ldots, Y_n) \tag{3}$$

The homogeneous translog form of (3) can be expressed by the Tornqvist index

$$\Delta \ln Y_t = \sum_{i=1}^{n} \bar{v}_{it} \Delta \ln Y_{it} , \tag{4}$$

where $\bar{v}_{it}$ is the arithmetic mean value share (over periods t and t-1) of $Y_i$ in total product.

Denoting the index of real factor input by Q, we express the functional relationship between Q and its components as

$$Q = f_Q(L, K, M), \tag{5}$$

where L is an index of aggregate labor services, K is an index of aggregate capital services and M is an index of aggregate materials services. The labor, capital and materials indexes are themselves functionally related to their components

$$K = f_K(K_1, K_2, \ldots, K_n). \tag{6}$$