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NBS Technical Note 1172

Productivity Measurement for the Construction Industry

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NBS technical note

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Stephen F. Weber
Barbara C. Lippiatt

Center for Applied Mathematics
National Engineering Laboratory
National Bureau of Standards
Washington, DC 20234

Prepared for:
Center for Building Technology
National Bureau of Standards
Washington, DC 20234

U.S. DEPARTMENT OF COMMERCE, Malcolm Baldrige, Secretary
NATIONAL BUREAU OF STANDARDS, Ernest Ambler, Director

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ABSTRACT

The fundamental concept underlying all productivity measures is a comparison of the output of a production process, an enterprise, an industry, or an economy with the corresponding factors of production (inputs) required to generate that output. Productivity measures are formulated as a ratio of output to one or more of the inputs. This report evaluates alternative productivity measures and concludes that the comprehensive Total Factor Productivity (TFP) method is preferred to the Single Factor Productivity method. To combine the multiple components in the denominator of a TFP index, a weighting system based on relative factor cost shares is recommended. A measurable index of the instantaneous rate of change in TFP between two time periods is derived from a general production function. The report also investigates the specific data requirements for implementing this TFP measure in the construction industry. An annotated bibliography is included.

Key words: construction industry; economics; index; input; output; productivity measurement; single factor productivity; total factor productivity.

PREFACE

This research was funded by the NBS Center for Building Technology. The authors wish to thank Michael Boehm for his assistance in searching for literature on productivity. Philip Schoech of Laurits R. Christensen Associates, Inc. deserves thanks for his advice on methods of quantifying inputs and outputs for measuring industry productivity. Through their comments and helpful suggestions, the following NBS reviewers contributed significantly to this final report: Robert Chapman, James Gross, Harold Marshall, Mary Natrella, Fred Rudder, and Richard Wright.

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1. INTRODUCTION

This report summarizes the results of an investigation into methods for measuring productivity and their application to the U.S. construction industry. The fundamental concept underlying all productivity measures is a comparison of the output of a production process, an industry, or an economy with the corresponding factors of production (inputs) required to generate that output. The output and inputs of production thus constitute the basic components of every productivity measure. Typically, productivity measures are formulated as a ratio of output to one or more of the inputs. Methods of deriving quantitative measures of these output and input components of productivity indexes are discussed in section 2. If only one of the inputs is used in the denominator, then the ratio is a single factor productivity measure. A common example of this type of measure is output per labor hour. Single factor productivity measures will be discussed in section 3. If all of the inputs are used, then the ratio is a total factor productivity measure. The main problem in developing a total factor productivity ratio concerns the proper weighting system to use when combining the individual input components into an index to serve as the denominator. In section 4, a mathematical model of the production process is used to develop the theoretically appropriate weighting system for combining input components. In addition to discussing these two basic types of productivity measures and their application to the construction industry, this report provides an annotated bibliography on productivity measurement. The three parts of this bibliography found in the Appendix deal with general productivity measurement methods, productivity in the construction industry, and case studies of productivity measurement.

2. COMPONENTS OF PRODUCTIVITY INDEXES

The development of both single and total factor productivity indexes requires accurate measures of output and input quantities. Ideally, these components of productivity indexes are denominated in physical units of measurement. Such data become less available, however, as levels of economic activity become more aggregated. Thus, one typically uses quantity indexes that are obtained by deflating to their constant dollar equivalent, the current dollar values corresponding to the physical quantities in order to correct for price changes. Other measurement considerations that apply to all components include: (1) development of an appropriate weighting system if heterogeneous items comprise a single component; (2) adjustment for changes in component quality over time; and (3) inclusion of new outputs and inputs introduced into the production process.[1]

2.1 OUTPUT

It is easier to establish meaningful measures of the quantity of output for industries and processes, the more homogeneous that output is. For example, a figure for bushels of wheat produced is more meaningful than is the number of buildings constructed. If meaningful quantity data are not available, the appropriate dollar measure of output is receipts plus increases (minus decreases) in the value of finished good inventories.[2] Since the contract construction industry does not hold inventories, but rather receives payment based upon completion (or progress toward completion) of work, the value of receipts need not be adjusted for inventory changes. On the other hand, such an adjustment should be made to receipts of Operative Builders, who are defined as "builders primarily engaged in construction of single family houses and other buildings for sale on their own account rather than as contractors."[3] When measuring industry productivity, it is important to exclude from the output measure receipts for subcontracted construction work, in order to avoid double counting.[4] In addition, receipts for nonconstruction activities such as architectural services and mortgage banking should be excluded, unless these activities are the object of the productivity measurement.

If output is to be measured by receipts (and inventory changes), this figure should be deflated with an index of output prices rather than of input costs.

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[1] Component measurement issues are also discussed in studies by the National Research Council (see Appendix, subsection A.1), Adam and Dogramaci, Greenberg, Kendrick and Creamer, and Siegel (see Appendix, subsection A.3).

[2] Memorandum by Philip E. Schoech, Laurits R. Christensen Associates, Madison, WI, May 27, 1981.

[3] U.S. Office of Management and Budget, Standard Industrial Classification Manual: 1972 (Washington, DC: U.S. Government Printing Office, 1972), p. 47.

[4] When measuring the productivity of construction projects, however, revenues that cover subcontracted work could be included in the output measure.

Input cost indexes do not provide the necessary adjustments for possible changes in profit margins (i.e., output prices) nor in productivity itself.[1] For example, suppose receipts increased solely as a result of increased output prices, while output quantities, input quantities and input prices remained constant. The input cost index used to deflate receipts would leave them unchanged. As a result, productivity would appear to increase, although the ratio of real output to real input had not changed. Conversely, suppose productivity had actually increased through an increase in output quantities while input quantities remained constant. If output prices were constant while input prices increased, then the use of an input cost index to deflate receipts would incorrectly diminish the measured productivity increase.

2.2 LABOR INPUT

Labor input can be denominated in labor hours actually worked adjusted for changes in the mix of labor categories employed. Hours worked (hours paid less holiday and leave hours) is preferred over hours paid as the measure of labor hours because productivity indexes are meant to deal with technological relationships between output and inputs. An hour paid but not worked simply raises the compensation paid for each hour actually worked. Changes in the labor mix can be accounted for by weighting the number of hours worked for each labor category by the value of its contribution to output. If we assume a competitive labor market, so that each labor category is paid a wage equal to its marginal contribution to output, then we can weight hours worked of each labor category by the corresponding average hourly earnings.

A measure of labor input equivalent to that of weighted labor hours can be obtained by deflating total labor compensation with an index of average hourly earnings. This index should be weighted to reflect the relative size of each labor category, the weights varying in accordance with the labor mix.[2]

2.3 MATERIALS INPUT

Materials input refers to all inputs not classified as labor or capital. In dollar terms, it is the value of output minus the value that is added to purchased goods and services by a firm's production processes. Since the materials used by one firm are the outputs produced by other firms, materials measurement issues are similar to those discussed for output in subsection 2.1.

2.4 CAPITAL INPUT

Capital input is by far the most difficult component of productivity indexes to quantify. Unlike materials, measurable quantities of which are completely

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[1] H. Kemble Stokes, Jr., "An Examination of the Productivity Decline in the Construction Industry," The Review of Economics and Statistics, Vol. 63, No. 4 (November 1981), pp. 495-502.

[2] John W. Kendrick and Daniel Creamer, Measuring Company Productivity: Handbook with Case Studies, Studies in Business Economics, No. 89 (New York: National Industrial Conference Board, Inc., 1965), pp. 33-36.

consumed during the current time period, capital provides a flow of services that extends beyond the current period. Moreover, although capital is similar to labor in that both provide a service flow, service prices and service price indexes can be readily observed for labor but not for capital. Thus, data are rarely available that can directly measure capital's contribution to production over the relevant time periods. Real (i.e., constant dollar) capital input must therefore be derived by one of several alternative estimating procedures. In general, these procedures arrive at real capital input by multiplying real capital stock by a ratio that reflects the value of capital services per period per unit of capital stock. The differences in these procedures include whether they use stock measures that are gross or net of depreciation, whether they adjust estimated stocks for rates of utilization, and whether they adjust for capital quality change.

Real capital stock can be estimated using the perpetual inventory method. As implemented by Caves, Christensen, and Swanson,[1] this method cumulates, by capital type, a lengthy time series of investment expenditures that has been deflated by an investment price index and adjusted for real capital depreciation. Real net capital stocks are then estimated by adding these cumulated, adjusted investment expenditures to an observation of real capital stock at the beginning of the time series and then summing across capital types. A less rigorous estimate of net capital stocks can be obtained by converting book values of capital stocks to market values by applying a standard ratio of book-to-market value for each capital type.[2] Alternatively, a measure of gross capital stock can be obtained by transforming book values into constant dollar acquisition prices by taking the age profile of capital into account.[3]

Unit costs of capital services are typically estimated by some measure of the real rates of return to capital types. An important issue here is the appropriate role for depreciation allowances. Another issue is whether to weight annual estimates of capital stocks by a single base-year rate of return, or by the real rate of return relevant for each year.

There is some question as to the proper treatment of rented capital. Since rental payments are made to other firms in return for their services during the current period, rented capital can be considered a materials input. Alternatively, it can be treated as capital, and deflated rental payments can be used to reflect real rented capital input.

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[1] D. W. Caves, L. R. Christensen, and J. A. Swanson, "Productivity in U.S. Railroads, 1951-1974," Discussion Paper #7909 (Madison, WI: University of Wisconsin, Madison, April 1979), pp. A5-A8.

[2] Memorandum of Philip E. Schoech, May 27, 1981.

[3] National Research Council, Panel to Review Productivity Statistics, Measurement and Interpretation of Productivity (Washington, DC: National Academy of Sciences, 1979), p. 130.

All components of a given productivity index must be measured consistently. First, the output and input measures must reflect the same economic activity. If the output measure excludes some activity of the firm (e.g., force account construction[1]), then the inputs that contribute to that activity should be excluded from the input measure(s). Secondly, all indexes used to construct component measures must have the same base year, the year in which the index is set at 100.0. Finally, every effort should be made to collect component data from the same source to ensure comparability.

[1] Force account construction is defined as "...construction work performed by an establishment primarily engaged in some business other than construction, for its own account and use and by its own employees...." U.S. Office of Management and Budget, Standard Industrial Classification Manual: 1972, p. 46.

3. SINGLE FACTOR PRODUCTIVITY MEASUREMENT

Single factor productivity (SFP) indexes measure the ratio of output to one input, usually labor. These single factor indexes require a limited amount of data, are relatively easy to calculate, and are widely used. In many cases, however, they inaccurately represent the course of technological change. This section summarizes information relevant to SFP in the construction industry, and then illustrates the shortcomings of SFP measures.

3.1 CONSTRUCTION INDUSTRY STATISTICS

Data relevant to construction industry single factor productivity measurement are available in two basic forms: (1) productivity indexes, and (2) studies of labor and materials requirements. Each will be discussed in turn.

3.1.1 Productivity Indexes

The Bureau of Labor Statistics (BLS) publishes an annual bulletin entitled Productivity Indexes for Selected Industries. The 1979 edition (Bulletin 2054 released 12/79) of this annual series included 88 industries and designated them by Standard Industrial Classification (SIC) number. Although this publication includes neither the construction industry as a whole nor its various segments, a number of construction-related industries are explicitly included, such as: sawmills and planing mills, general (SIC 2421), veneer and plywood (SIC 2435, 2436), hydraulic cement (SIC 3241), structural clay products (SIC 325), clay construction products (SIC 325, 3253, 3259), and concrete products (SIC 3271, 3272). For each of these industries the bulletin publishes time-series indexes of output per employee and output per employee hour going back to the 1950's.

In addition to these published data on productivity, BLS can make available unpublished data in the same form for 549 other industries. Of these industries at least 50 are related to the construction industry, ranging from prefabricated wood buildings and structural wood members (SIC 2452), to flat glass (SIC 3211), mineral wool (SIC 3296), and construction machinery (SIC 3531).

Besides this information on construction-related industries, the BLS can make available on an unpublished basis some data on the construction industry taken as a whole. Computer print-outs of time series index numbers (1967 = 100) going back to 1947 are available for a number of key variables describing the construction industry. These annual statistics include: total output in constant dollars, total output in current dollars, compensation paid to all employees, number of employees, number of hours paid, nonlabor payments, nominal compensation per hour, real compensation per hour, unit labor costs, unit nonlabor payments, implicit price deflator, average weekly hours, and most importantly for those concerned with productivity, output per employee and output per employee hour. An example of these annual index series is presented in table 3.1 for output per employee hour in the construction industry. The print-outs also present, in a matrix format, the annual rates of growth derived from these time series index numbers for every pairwise combination of years throughout the entire time series. An example of these unpublished computer

Table 3.1 Annual Index Values for Output per Employee Hour in the U.S. Construction Industry, 1947-1979 (1967 = 100)

Year	Index	Year	Index
1947	55.2	1964	93.1
1948	59.6	1965	95.7
1949	59.9	1966	96.3
1950	63.2	1967	100.0
1951	64.2	1968	103.6
1952	65.6	1969	94.0
1953	68.8	1970	89.4
1954	72.1	1971	86.2
1955	72.3	1972	84.6
1956	72.3	1973	80.1
1957	74.6	1974	77.2
1958	80.3	1975	78.4
1959	81.8	1976	81.3
1960	84.9	1977	79.9
1961	87.0	1978	74.3
1962	88.3	1979	68.9
1963	88.5		

Source: U.S. Department of Labor, Bureau of Labor Statistics.

print-outs is given in table 3.2. To find the rate of growth for any given period, read down the left-hand column stopping at the beginning year of the period. Then read across that row to the column corresponding to the ending year of the period of interest. The number thus found at the intersection of the beginning year row and the ending year column is the annual rate of growth in percent between those two years. For example, output per labor hour declined by 2.2 percent annually during the nine year period from 1970 to 1979. Each rate of growth shown in table 3.2 represents the slope coefficient, multiplied by 100, of the least squares regression of the natural logarithm of the output per employee hour index on the year index, for all the years in each period. The algebraic expression for this slope coefficient is

$$\frac{n \sum_{i=1}^{n} i \ln P_i - \left(\sum_{i=1}^{n} i\right)\left(\sum_{i=1}^{n} \ln P_i\right)}{n \sum_{i=1}^{n} i^2 - \left(\sum_{i=1}^{n} i\right)^2},$$

where $i = 1, 2, \ldots, n$, the year index for each year in the period, including the beginning and ending years; and

P_i = annual index (1967 = 100) for the i^{th} year, of output per employee hour in the U.S. construction industry, as presented in table 3.1.

3.1.2 Labor and Materials Requirements Studies

Another useful source of information related to productivity in the construction industry is a series of studies on the labor and materials requirements for various construction industry sectors.[1] Each sector is devoted to a specific type of construction project. The project types that have been studied include: civil works construction, college housing construction, Federally aided highways, Federal office buildings, hospitals, private multifamily housing, private singlefamily housing, public housing, schools, and sewer works. These studies present data on the number of onsite and offsite employee hours used in a sample of projects per $1000 of total contract cost. Some of these studies also report employee hours per square foot of floor area.

3.2 LIMITATIONS OF SINGLE FACTOR PRODUCTIVITY MEASURES

One purpose of measuring productivity is to determine whether and to what extent technological change has occurred over time in a production process, an individual firm or plant, an industry, or even an entire economy. Alternatively, productivity measures may be used to compare two processes, firms, industries, or economies at the same point in time to determine which entity is technologically superior. Both purposes involve the comparison of technologies.

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[1] For example, see Robert J. Prier, "Labor Requirements Decline for Public Housing Construction," Monthly Labor Review, Vol. 103, No. 12 (December 1980), pp. 40-44.

Table 3.2 Annual Rates of Growth for Output per Employee Hour in the U.S. Construction Industry, by Beginning and Ending Year of Period, 1947 - 1979 (Percent)[a,b]

Beginning Year	Ending Year 1950	1955	1958	1959	1960	1961	1962	1963	1964	1965	1966
1947	4.2	3.3	3.0	3.0	3.1	3.1	3.1	3.0	3.0	3.0	2.9
1948	3.0	3.1	2.9	2.9	3.0	3.0	3.0	2.9	2.9	2.9	2.8
1949	5.6	3.3	2.9	3.0	3.0	3.0	3.0	2.9	2.9	2.9	2.9
1950		3.1	2.8	2.9	3.0	3.0	3.0	2.9	2.9	2.9	2.8
1951		3.4	2.9	2.9	3.0	3.1	3.0	2.9	2.9	2.9	2.8
1952		3.4	2.8	2.9	3.0	3.1	3.0	2.9	2.9	2.9	2.8
1953		2.5	2.5	2.8	2.9	3.0	3.0	2.8	2.8	2.8	2.7
1954		0.4	2.5	2.8	3.0	3.1	3.0	2.8	2.8	2.8	2.7
1955			3.5	3.6	3.6	3.5	3.3	3.0	3.0	2.9	2.8
1956			5.4	4.5	4.2	3.9	3.5	3.1	3.0	3.0	2.8
1957			7.6	4.7	4.1	3.7	3.3	2.8	2.8	2.8	2.7
1958				1.9	2.8	2.8	2.6	2.1	2.3	2.4	2.4
1959					3.7	3.1	2.6	2.0	2.3	2.4	2.3
1960						2.6	2.0	1.4	2.1	2.3	2.2
1961							1.5	0.9	2.1	2.5	2.3
1962								0.2	2.7	3.0	2.5
1963									5.2	4.0	2.8
1964										2.8	1.7
1965											0.6
1966											
1967											
1968											
1969											
1970											
1971											
1972											
1973											
1974											
1975											
1976											
1977											
1978											

Beginning Year	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979
1947	2.9	2.9	2.7	2.5	2.3	2.1	1.9	1.7	1.5	1.4	1.3	1.1	0.9
1948	2.8	2.8	2.7	2.5	2.2	2.0	1.8	1.6	1.4	1.3	1.2	1.0	0.8
1949	2.8	2.8	2.7	2.4	2.2	2.0	1.7	1.5	1.3	1.2	1.1	0.9	0.7
1950	2.8	2.8	2.6	2.4	2.1	1.9	1.6	1.4	1.2	1.1	0.9	0.8	0.6
1951	2.8	2.8	2.6	2.3	2.1	1.8	1.6	1.3	1.1	1.0	0.8	0.7	0.5
1952	2.8	2.8	2.6	2.3	2.0	1.7	1.4	1.2	1.0	0.8	0.7	0.5	0.3
1953	2.7	2.7	2.5	2.2	1.9	1.6	1.3	1.0	0.8	0.7	0.5	0.4	0.2
1954	2.7	2.7	2.5	2.1	1.8	1.5	1.2	0.9	0.7	0.5	0.4	0.2	0.0
1955	2.8	2.8	2.5	2.1	1.7	1.4	1.1	0.7	0.5	0.4	0.3	0.1	-0.1
1956	2.8	2.8	2.4	2.0	1.6	1.2	0.9	0.6	0.3	0.2	0.1	-0.1	-0.3
1957	2.6	2.7	2.3	1.8	1.4	1.0	0.6	0.3	0.1	0.0	-0.1	-0.3	-0.5
1958	2.4	2.5	2.0	1.6	1.1	0.7	0.3	0.0	-0.2	-0.3	-0.4	-0.6	-0.8
1959	2.4	2.5	2.0	1.4	0.9	0.5	0.1	-0.3	-0.5	-0.5	-0.6	-0.8	-1.0
1960	2.3	2.5	1.9	1.2	0.6	0.2	-0.2	-0.6	-0.8	-0.8	-0.9	-1.0	-1.2
1961	2.4	2.6	1.8	1.0	0.4	-0.1	-0.5	-0.9	-1.1	-1.1	-1.1	-1.2	-1.4
1962	2.6	2.7	1.7	0.8	0.1	-0.4	-0.8	-1.2	-1.4	-1.3	-1.3	-1.5	-1.6
1963	2.8	2.9	1.6	0.5	-0.3	-0.8	-1.3	-1.6	-1.8	-1.7	-1.6	-1.7	-1.9
1964	2.2	2.6	0.9	-0.3	-1.1	-1.5	-1.9	-2.2	-2.3	-2.1	-2.0	-2.0	-2.2
1965	2.2	2.8	0.4	-1.1	-1.9	-2.2	-2.5	-2.8	-2.7	-2.5	-2.3	-2.3	-2.4
1966	3.8	3.7	-0.4	-2.1	-2.8	-2.9	-3.2	-3.3	-3.2	-2.8	-2.5	-2.5	-2.6
1967		3.6	-3.1	-4.2	-4.3	-4.0	-4.1	-4.0	-3.7	-3.1	-2.7	-2.6	-2.8
1968			-9.3	-7.1	-5.8	-4.8	-4.6	-4.4	-3.8	-3.1	-2.6	-2.6	-2.7
1969				-4.8	-4.2	-3.5	-3.7	-3.7	-3.2	-2.4	-2.0	-2.1	-2.4
1970					-3.6	-2.7	-3.4	-3.6	-2.9	-2.0	-1.6	-1.8	-2.2
1971						-1.8	-3.6	-3.8	-2.8	-1.6	-1.2	-1.5	-2.0
1972							-5.4	-4.5	-2.6	-1.0	-0.6	-1.2	-2.0
1973								-3.6	-1.1	0.6	0.5	-0.7	-1.8
1974									1.5	2.6	1.4	-0.6	-2.1
1975										3.8	1.0	-1.8	-3.4
1976											-1.7	-4.4	-5.5
1977												-7.1	-7.1
1978													-7.2

a Data are correct as of May 29, 1980.

b The annual percentage rate of growth represents the slope coefficient, multiplied by 100, of the least squares regression of the natural logarithm of the output per employee hour index on the year index, for all the years in each period:

$$\frac{n \sum_{i=1}^{n} i \ln P_i - \left(\sum_{i=1}^{n} i\right)\left(\sum_{i=1}^{n} \ln P_i\right)}{n \sum_{i=1}^{n} i^2 - \left(\sum_{i=1}^{n} i\right)^2},$$

where $i = 1,2,\ldots, n$, the year index for each year in the period, including the beginning and ending years; and

P_i = annual index (1967 = 100) for the i^{th} year, of output per employee hour in the U.S. construction industry, as presented in table 3.1.

Source: U.S. Department of Labor, Bureau of Labor Statistics.

Technology is here to be interpreted in the broad sense as the entire process required in transforming inputs to outputs. Thus technological change may arise from innovations in equipment, organization, information, or management.

In certain very restricted situations, SFP measures are able to confirm the occurrence of technological change. For example, if only one input such as labor is reduced while output and all the other inputs remain unchanged, then the resulting increase in labor productivity (output per labor hour) would be sufficient to confirm that technological change has occurred. Similarly, if all inputs remain unchanged or decrease while output increases, then all of the SFP measures would increase. In this case, any one of these measures would confirm the occurrence of technological change. Neither of these restrictive situations in which SFP successfully tests for technological change permits more than one input quantity to change. In practice, however, most changes in technology require the substitution of one input for another, so that SFP indexes are rarely useful in measuring technological change.

The hypothetical example in table 3.3 serves to illustrate the ambiguities that result when SFP measures are used to identify technological change. Column 3 indicates that while quantities of output, labor input, and materials input have all increased from period 1 to period 2, the use of capital has declined. Column 4 presents the SFP measure for each input, derived by dividing the index of change for output (i.e., 1.100) by that input's index of change. A value less than one indicates a decline in productivity, equal to one no change, and greater than one an increase in productivity. Thus, in this example, labor productivity has declined, materials productivity has remained constant, and capital productivity has increased. If one measured labor productivity only, a technological setback would be indicated, whereas if capital were selected instead, one would conclude that a positive technological change had occurred. In fact, the actual cause of the SFP changes may not have been technological change at all. For example, another common cause of SFP changes is a mere shift in relative prices, which in turn leads to substitution between inputs.[1] Thus, in this illustration, labor productivity may have fallen and capital productivity risen simply because the price of labor fell relative to the price of capital, causing substitution of labor for capital. Alternatively, the measured changes in SFP may have arisen from some combination of technological and relative price changes. This potential ambiguity in SFP indexes suggests that a broader measure of technological change is needed. Such a measure is discussed in the next section.

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[1] Edwin Mansfield, Microeconomics: Theory and Applications, 3rd edition (New York: W.W. Norton and Company, 1979), pp. 516-517.

Table 3.3 Single Factor Productivity Measurement: An Illustration

Productivity Component	Quantity[a] Period 1 (1)	Period 2 (2)	Index of Change (3)=(2)/(1)	Single Factor Productivity Measure (4)=1.100/(3)
Output	500	550	1.100	N/A
Input				
Labor	130	150	1.154	0.95
Materials	100	110	1.100	1.00
Capital	80	70	0.875	1.26

[a] Quantities can be denominated either in physical units of measurement or in quantity index numbers derived by dividing current dollar values by their appropriate price indexes, as discussed in section 2.

4. TOTAL FACTOR PRODUCTIVITY MEASUREMENT

As demonstrated in the previous section, SFP measures are ambiguous because they only take account of one factor of production. The value of the SFP measure of a given production process or entire industry depends critically on which single factor of production is taken into account. Consequently, what is required for most analysis is a productivity index that takes account of all major inputs in the production process. Such a comprehensive index of productivity is usually referred to as a total factor productivity (TFP) index.

4.1 MEASUREMENT METHOD

Although several theoretical approaches to measuring the TFP of industries and individual firms have been developed,[1] the present discussion focuses on the TFP measurement method developed and applied to the railroad industry by Caves, Christensen, and Swanson.[2] The measurement procedure proposed by Caves et al. has been selected because it avoids restrictive assumptions about the form of the underlying production function selected to represent an industry or firm. A production function shows the maximum obtainable output rates for all possible sets of input usage rates and, by definition, specifies a particular technology. Caves et al. begin by assuming that output Y is produced by combining a set of inputs X_i according to a general implicit production function:[3]

$$f\ (Y;\ X_1,\ X_2,\ .\ .\ .,\ X_n;\ T) = 0, \tag{4.1}$$

where T is time, which allows for shifts over time in the production function. Such shifts in the production function are equivalent to changes in technology, which could represent changes in productivity. Using a duality theorem developed by McFadden,[4] the following unique cost function corresponding to the production function given by eq (4.1) can be specified:

$$C = g\ (Y;\ W_1,\ W_2,\ .\ .\ .,\ W_n;\ T), \tag{4.2}$$

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[1] The four basic approaches to measuring TFP are summarized briefly in an article by W. Erwin Diewert, "The Theory of Total Factor Productivity Measurement in Regulated Industries," in Thomas G. Cowing and Rodney E. Stevenson, eds., Productivity Measurement in Regulated Industries (New York: Academic Press, 1981), pp. 17-44.

[2] Douglas W. Caves, Laurits R. Christensen, and Joseph A. Swanson, "Productivity in U.S. Railroads, 1951-1974," The Bell Journal of Economics, Vol. 11, No. 1 (Spring 1980), pp. 166-181.

[3] The production function employed by Caves et al. is more general than that specified in eq (4.1) in that the former allows for more than one output.

[4] D. L. McFadden, "Cost Revenue and Profit Functions," in M. A. Fuss and D. L. McFadden, eds., Production Economics: A Dual Approach to Theory and Applications (Amsterdam: North Holland, 1978).

where W_i is the price of input X_i and C is total cost:

$$C = \sum_{i=1}^{n} W_i X_i. \tag{4.3}$$

By taking the natural logarithm of the cost function, eq (4.2), and totally differentiating with respect to time, Caves et al. allocate the rate of growth of cost among changes in the output level, changes in input prices, and shifts in the cost function (i.e., productivity changes in the opposite direction), respectively:

$$\frac{d\ln C}{dT} = \frac{\partial \ln g}{\partial \ln Y} \frac{d\ln Y}{dT} + \sum_{i=1}^{n} \frac{\partial \ln g}{\partial \ln W_i} \frac{d\ln W_i}{dT} + \frac{\partial \ln g}{\partial T}. \tag{4.4}$$

Following Shephard's lemma,[1] it can be shown that the first partial derivative of the logarithm of the cost function with respect to the logarithm of each input price is equal to the cost share of that input:

$$\frac{\partial \ln g}{\partial \ln W_i} = \frac{W_i X_i}{C} = S_i, \tag{4.5}$$

where S_i represents the cost share of the ith input. This useful characteristic of the cost function can be illustrated with the hypothetical data in table 4.1. Since the price of input i has increased by $1 between 1981 and 1982, if we hold output, technology, all input quantities, and all other prices constant, then total cost will increase by $200. Using 1981 as the base year, the continuous partial derivative, $\partial \ln g/\partial \ln W_i$, can be approximated with discrete data by the ratio of the percentage change in total cost to the percentage change in the price of input i, that is, [(10,200 - 10,000)/10,000]/ [(11 - 10)/ 10] = 0.2. Consequently, $\partial \ln g/\partial \ln W_i = S_i$, since the cost share of input i in the base year is [(10)(200)]/10,000 = 0.2.[2]

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[1] Ronald W. Shephard, Cost and Production Functions (Princeton: Princeton University Press, 1953), reprinted as Vol. 194 of the series, "Lecture Notes in Economics and Mathematical Systems," M. Beckmann and H. B. Künzi, eds., (New York: Springer-Verlag, 1981). As originally formulated by Shephard (pp. 10-11), this fundamental result states that the factor quantities that minimize the total cost of a production process are equal to the first partial derivatives of the cost function with respect to factor prices: $\partial g/\partial W_i = X_i$. Multiplying both sides of this equation by the ratio W_i/C, and noting that $C = g$ and $\partial Z/Z = \partial \ln Z$, yields eq (4.5).

[2] Alternatively, if 1982 is considered the base year, $\partial \ln g/\partial \ln W_i$ is approximated by [(10,000 - 10,200)/10,200]/[(10-11)/11] = 0.217, and the cost share of input i in the base year is also [(11)(200)]/10,200 = 0.217.

Table 4.1 Hypothetical Industry Data for Two Time Periods

Symbol	Definition	1981	1982
W_i	Price of Input i ($/Unit)	10	11
X_i	Quantity of Input i	200	200
C	Total Production Cost ($)	10,000	10,200

Caves et al. take the total derivative of the natural logarithm of eq (4.3) with respect to time and obtain:

$$\frac{d\ln C}{dT} = \sum_{i=1}^{n} \frac{W_i X_i}{C} \frac{d\ln W_i}{dT} + \sum_{i=1}^{n} \frac{W_i X_i}{C} \frac{d\ln X_i}{dT}. \tag{4.6}$$

Substitution of eq (4.6) into eq (4.4) and further substitution of eq (4.5) into the result yields the following expression for productivity change:

$$-\frac{\partial \ln g}{\partial T} = \frac{\partial \ln g}{\partial \ln Y} \frac{d\ln Y}{dT} - \sum_{i=1}^{n} S_i \frac{d\ln X_i}{dT} . \tag{4.7}$$

If the production process exhibits the economic property known as constant returns to scale, this equation can be further simplified. Constant returns to scale means that an increase (decrease) in the quantities used of all inputs by the same proportion will lead to an increase (decrease) in output by exactly the same proportion. That is, any percentage change in inputs will lead to an equal percentage change in output.[1] Furthermore, if input markets are competitive, then the firm cannot influence input prices. As a result, the given percentage change in inputs will lead to the same percentage change in total cost. Therefore, the percentage change in total cost is equal to the percentage change in output, and the partial derivative $\partial \ln g/\partial \ln Y$ can be assumed to be equal to one. The equation for productivity change then becomes:[2]

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[1] For a given industry and time period, this assumption may be valid only over a limited range of output levels.

[2] This definition of the change in TFP derived here following Caves et al. is identical to that used by Leo Sveikauskas in a recent study of the effect of technological inputs on industry TFP. See "Technological Inputs and Multifactor Productivity Growth," Review of Economics and Statistics, Vol. 63, No. 2 (May 1981), pp. 275-282.

$$-\frac{\partial \ln g}{\partial T} = \frac{d\ln Y}{dT} - \sum_{i=1}^{n} S_i \frac{d\ln X_i}{dT} . \qquad (4.8)$$

In order to apply this index to discrete (e.g., annual) data, Caves et al. recommend the use of first differences in natural logarithms and of beginning and end-of-period averages for the input cost shares. Implementing this recommendation for eq (4.8), one obtains the following formula for measuring the rate of growth in TFP compounded continuously over the time period T-1 to T:[1]

$$\text{TFP Growth Rate} = \ln Y_T - \ln Y_{T-1} - \sum_{i=1}^{n} \frac{1}{2}(S_{i,T} + S_{i,T-1})(\ln X_{i,T} - \ln X_{i,T-1}). \qquad (4.9)$$

The application of eq (4.9) can be illustrated with the hypothetical data in table 4.2. The right-hand side of eq (4.9) would be evaluated in the following manner:

$$\begin{aligned} \ln 110 - \ln 100 &- \frac{1}{2}(0.082 + 0.115)(\ln 30 - \ln 40) \\ &- \frac{1}{2}(0.150 + 0.115)(\ln 40 - \ln 30) \\ &- \frac{1}{2}(0.768 + 0.770)(\ln 2200 - \ln 2000) = 0.0122. \end{aligned}$$

This means that the continuous rate of growth in TFP between these two periods is approximately 1.2 percent. Since the data are given as annual values for successive years, this result is interpreted as a continuous annual rate of productivity increase of 1.2 percent.

4.2 APPLICATION TO CONSTRUCTION INDUSTRIES

Equation (4.9) could be applied to measure the changes in TFP for individual industries within the construction sector as well as for the sector as a whole. Every five years beginning with 1967, the Census of Construction Industries has been conducted. The most recent Census (1977) includes detailed information on employment, receipts, costs, and assets for the approximately 1.2 million establishments engaged in construction in the United States.[2] A construction establishment is an office or other place of business where such construction-related activities as estimating, bidding, scheduling, purchasing,

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[1] This formula can be equivalently written as

$$\ln (Y_T/Y_{T-1}) - \sum_{i=1}^{n} \frac{1}{2}(S_{i,T} + S_{i,T-1})\ln(X_{i,T}/X_{i,T-1}).$$

[2] For an excellent summary of the 1977 Census results and for more detailed descriptions of the variables included in the Census, see Abraham Goldblatt and Patrick MacAuley, "The 1977 Census of Construction—A Wealth of Economic Data," Construction Review, January 1981, pp. 4-12.

Table 4.2 Hypothetical Data on Output and Input Quantities, Input Prices, and Cost Shares of an Industry for Two Time Periods

		1981			1982		
Symbol	Variable	Quantity	Price ($/Unit)	Cost Share	Quantity	Price ($/Unit)	Cost Share
Y	Output	100	--	--	110	--	--
X_1	Labor	40	15	0.115	30	16	0.082
X_2	Capital	30	20	0.115	40	22	0.150
X_3	Materials	2000	2	0.770	2200	2.05	0.768

Table 4.3 Data Available in the 1977 Census of Construction

Type of data	Totals[1]	State and industry totals[2]	By employment size	By receipts size	By type of construction
Assets and depreciation:					
Gross book value—total	Yes	Yes	Yes	Yes	
Structures, machinery and equipment	Yes				
Accumulated depreciation—total, structures, machinery and equipment	Yes				
Net value—total, structures, machinery and equipment	Yes				
Depreciation charges—total, strucrures, machinery and equipment	Yes				
Capital expenditures:					
Total capital expenditures	Yes	Yes	Yes	Yes	
New structures, machinery and equipment	Yes				
Used structures, machinery and equipment	Yes				
Communication services, payments for	Yes				
Employees:					
All employees—average number	Yes	Yes	Yes	Yes	
Construction workers—average number	Yes	Yes			
Other employees—average number	Yes				
Employer costs for fringe benefits—legally required and voluntary expenditures	Yes				
Establishments, number of:					
All	Yes			Yes	
With payroll	Yes	Yes	Yes	Yes	Yes
Without payroll	Yes			Yes	
Materials and Energy:					
Materials, components, supplies, and fuels	Yes	Yes	Yes	Yes	
Selected power, fuels, and lubricants	Yes				
Payroll:					
First quarter, all employees	Yes				
Annual:					
All employees	Yes	Yes	Yes	Yes	
Construction workers	Yes	Yes			
Other employees	Yes				
Proprietors and working partners:					
All establishments	Yes			Yes	
Establishments with payroll	Yes			Yes	
Establishments without payroll	Yes			Yes	
Receipts:					
All business receipts:					
All establishments	Yes			Yes	
Establishments with payroll	Yes		Yes	Yes	
Establishments without payroll	Yes			Yes	
Construction receipts, total	Yes	Yes	Yes	Yes	Yes
For work subcontracted in from others	Yes				
Other business receipts and land receipts	Yes				
Net construction receipts	Yes	Yes	Yes	Yes	
Value added	Yes	Yes	Yes	Yes	
Rental payments:					
Total	Yes	Yes	Yes	Yes	
For machinery and equipment	Yes				
For structures	Yes				
Repairs to structures and related facilities	Yes				
Repairs to machinery and equipment	Yes				
Specialization within State	Yes				
Sub-contracting	Yes	Yes	Yes	Yes	

[1] For each four-digit industry at the national level, or for the entire construction industry for each state.
[2] For each four-digit industry in each state.

Source: Abraham Goldblatt and Patrick MacAuley, "The 1977 Census of Construction--A Wealth of Economic Data," Construction Review, January 1981, p. 5.

and supervising are conducted. Table 4.3 provides a list of the categories of data collected in the 1977 Census and indicates the level of detail available for each category.

The data on Net Construction Receipts, Construction Worker Payroll, and Materials and Energy make possible the derivation of quantity indexes for output, and for labor and materials which could be used in eq (4.9). This derivation would require the development and application of appropriate price and cost indexes to convert these current dollar Census values to corresponding quantity indexes, as explained in section 2. An appropriate quantity index for capital input is not as readily available. The perpetual inventory method for determining the real capital stock used in construction cannot be applied because the Census data do not go back far enough. The less regions approach based on the Gross Book Value data in the Census could be employed, provided an estimate of the average ratio of book-to-market value can be developed for the construction industry. Once real capital stocks have been estimated, they can be converted to real capital input by multiplying by the real rate of return to capital in the construction industry. The Rental Payments data could be deflated by an appropriate cost index and used to reflect real rented capital input.

Once the resulting data on all relevant input and output quantities have been obtained, eq (4.9) could be used to calculate estimates of TFP growth for the two five-year intervals between the years for which the Census of Construction Industries has been conducted: 1967, 1972, and 1977. These five-year estimates of TFP growth could be derived for the entire construction sector of the United States or of individual states. In addition, these estimates could be derived for individual construction industries at the four-digit Standard Industrial Classification (SIC) level, as listed in table 4.4.[1] For example, individual TFP growth estimates could be developed for Plumbing, Heating and Air Conditioning Contractors (SIC 1711) and for Roofing and Sheet Metal Work Contractors (SIC 1761). Alternatively, TFP growth estimates could be developed for groups of construction industries at the two- or three-digit SIC level. An example of a three-digit group of construction industries would be General Building Contractors-Residential Buildings (SIC 152); an example of a two-digit industry group would be Construction-Special Trade Contractors (SIC 17).

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[1] The definitions of some four-digit construction industries (e.g., General Contractors - Single-Family Houses (SIC 1521) have changed considerably between Censuses. For these industries it would not be possible to derive the five-year TFP growth estimates based on Census data.

Table 4.4 Standard Industrial Classification (SIC) Titles for Construction Industries

SIC code	Industry titles
15	**BUILDING CONSTRUCTION—GENERAL CONTRACTORS AND OPERATIVE BUILDERS**
152	**General Building Contractors—Residential Buildings**
1521	General Contractors—Single-Family Houses
1522	General Contractors—Residential Buildings, Other Than Single-Family
153	**Operative Builders**
1531	Operative Builders
154	**General Building Contractors—Nonresidential Buildings**
1541	General Contractors—Industrial Buildings and Warehouses
1542	General Contractors—Nonresidential Buildings, Other Than Industrial Buildings and Warehouses
16	**CONSTRUCTION OTHER THAN BUILDING CONSTRUCTION—GENERAL CONTRACTORS**
161	**Highway and Street Construction, Except Elevated Highways**
1611	Highway and Street Construction, Except Elevated Highways
162	**Heavy Construction, Except Highway and Street Construction**
1622	Bridge, Tunnel, and Elevated Highway Construction
1623	Water, Sewer, Pipe Line, Communication and Power Line Construction
1629	Heavy Construction, Not Elsewhere Classified
17	**CONSTRUCTION—SPECIAL TRADE CONTRACTORS**
171	**Plumbing, Heating (Except Electric), and Air Conditioning**
1711	Plumbing, Heating (Except Electric), and Air Conditioning
	CONSTRUCTION—SPECIAL TRADE CONTRACTORS—Continued
172	**Painting, Paper Hanging, and Decorating**
1721	Painting, Paper Hanging, and Decorating
173	**Electrical Work**
1731	Electrical Work
174	**Masonry, Stonework, Tile Setting, and Plastering**
1741	Masonry, Stone Setting, and Other Stonework
1742	Plastering, Drywall, Acoustical and Insulation Work
1743	Terrazzo, Tile, Marble, and Mosaic Work
175	**Carpentering and Flooring**
1751	Carpentering
1752	Floor Laying and Other Floorwork, Not Elsewhere Classified
176	**Roofing and Sheet Metal Work**
1761	Roofing and Sheet Metal Work
177	**Concrete Work**
1771	Concrete Work
178	**Water Well Drilling**
1781	Water Well Drilling
179	**Miscellaneous Special Trade Contractors**
1791	Structural Steel Erection
1793	Glass and Glazing Work
1794	Excavating and Foundation Work
1795	Wrecking and Demolition Work
1796	Installation or Erection of Building Equipment, Not Elsewhere Classified
1799	Special Trade Contractors, Not Elsewhere Classified
6552	Subdividers and Developers, Except Cemeteries

Source: U.S. Department of Commerce, Bureau of the Census, 1977 Census of Construction Industries, Washington, D.C., 1980.

APPENDIX A. ANNOTATED BIBLIOGRAPHY ON PRODUCTIVITY MEASUREMENT

A.1 PRODUCTIVITY MEASUREMENT METHODS

Caves, Douglas W.; Christensen, Laurits R.; and Swanson, Joseph A., "Productivity in U.S. Railroads, 1951-1974," The Bell Journal of Economics, Vol. 11, No. 1 (Spring 1980), pp. 166-181. Includes 21 bibliographical references.

This article develops estimates of U.S. railroad total factor productivity by using methods based on the neoclassical theory of production. The authors find that railroad productivity grew at the average annual rate of 1.5 percent per year during the 1951-1974 period. Using conventional measurement procedures for comparison, they find productivity growth of 3.6 percent per year. The lower estimate of 1.5 percent is the result of using procedures which better represent the railroad production process. These include using (1) estimated cost elasticities of the outputs, rather than revenue shares, as output weights, (2) actual cost shares, rather than national income shares, as input weights and (3) input and output weights which change annually.

Diewert, W. Erwin, "The Theory of Total Factor Productivity Measurement in Regulated Industries," in Productivity Measurement in Regulated Industries (edited by Thomas G. Cowing and Rodney E. Stevenson). New York: Academic Press, 1981, pp. 17-44. The book includes 13 pages of bibliographical references.

This paper reviews those aspects of duality theory that are relevant to the measurement of total factor productivity (TFP) for a competitive firm. Four alternative approaches are presented: (i) the econometric estimation of production and cost functions; (ii) the use of Divisia indexes; (iii) the use of exact index numbers; and (iv) nonparametric methods for measuring technical progress. Each of these approaches is then applied to the special case of a rate-of-return regulated firm, and the necessary assumptions required for each case, regulated as well as competitive, are derived. The informational requirements for measuring TFP for a regulated firm using each of three different approaches--(ii), (iii), and (iv)--are also derived.

Gold, Bela, "Improving Industrial Productivity and Technical Capabilities: Needs, Problems, and Suggested Policies," in Productivity Analysis: A Range of Perspectives (edited by Ali Dogramaci). Boston: Martinus Nijhoff Publishing, 1981, pp. 86-132. Includes 29 bibliographical references.

The author first reviews the objectives of policies to accelerate progress in industrial productivity and technical capabilities. He then discusses the sources and prospective effects of productivity and technological gains. This is followed by examination of the considerations confronted by those deciding whether to increase or decrease resource commitments to such improvement programs. The final focus is on the policy implications of such considerations. Key findings emphasize that productivity changes have generally been inadequately measured, that the relative importance of the factors affecting them has changed substantially since World War II, that such primary determinants differ among industries, and the the effects of productivity increases are often widely at variance with expectations.

Gorman, John A., "Nonfinancial Corporations: New Measures of Output and Input," Survey of Current Business, Vol. 52 (March 1972), pp. 21-27, 33. No references.

This article presents data that provide a basis for studying productivity and costs of nonfinancial corporations. Specifically, the data consist of annual estimates of nonfinancial corporations' output, of capital stocks and inputs, of labor inputs consistent with the Bureau of Economic Analysis compensation and employment series, of combined labor and capital inputs, and of profits. The output, profit, and stock estimates are based on the assumption of consistent depreciation practices. Total factor productivity is estimated, as well as the partial productivity of labor and capital separately. Also, rates of return to capital stock are calculated, relating property income to the capital stock valued at current replacement cost.

Mark, Jerome A., "Productivity Measurement," in Productivity: Prospects for Growth (edited by Jerome M. Rosow). New York: Van Nostrand Reinhold Company, 1981, pp. 54-75. Includes 11 bibliographical references in footnotes.

To provide a basis for understanding the present status and future direction of productivity measurement, this chapter examines the productivity measures currently available, some of their limitations, how they can be improved, and what attempts are being made to improve them. The examination traces the available measures of the Federal Government as well as those of the principal private researchers in the field, summarizes the conceptual bases of the indicators, and points out some of the more fundamental differences in approaches employed.

Nadiri, M. Ishaq, "Some Approaches to the Theory and Measurement of Total Factor Productivity: A Survey," Journal of Economic Literature, Vol. 8, No. 4 (December 1970), pp. 1137-1177. Includes 155 bibliographical references.

This survey concentrates on some basic theoretical hypotheses and empirical evidence regarding the measurement and determinants of total factor productivity change in the U.S. economy. Section I comprises a preliminary review of the indices of productivity, some empirical evidence, and a brief discussion of the forces which may govern the behavior of productivity changes. Section II briefly covers the problems of aggregation underlying the aggregate production function, and some theoretical issues on the nature of technical change and problems of its diffusion. The next two sections are devoted to the calculation of technical change based on the aggregate production function. In the final section, the author concludes that an important contribution towards understanding the determinants of technological change has been made by the theories of endogenous technological change and the attempts to explain the production and transmission of new knowledge. Further, the formulation of more general forms of the production function via cost functions has served to widen the scope of research in a new direction.

National Research Council, Panel to Review Productivity Statistics, Measurement and Interpretation of Productivity. Washington, D.C.: National Academy of Sciences, 1979, 449 pp. Includes 7 pages of bibliographical references.

This work provides a survey of productivity theory and ten papers on specific topics related to productivity. The survey consists of nine chapters, four of which are particularly useful for those interested in productivity measurement. Chapter 3 reviews the basic concept of a production function and derives some of the statistical formulas used in productivity measurement. Chapters 5 and 6 contain a discussion of shortcomings in existing measures and possible ways of improving them. Chapter 5 discusses the measurement of output, the numerator of the productivity ratio. The first part of this chapter establishes criteria for the inclusion or exclusion of specific types of activity in the measure of output used in measuring productivity; the second part discusses the measurement of inputs (labor, capital services, and intermediate inputs), one or more of which make up the denominator of the productivity ratio. The problems in measuring labor input include the appropriate concept of hours of work and whether labor input should be differentiated by some measure of its composition, such as skill, experience, or education. The problems of measuring the input of capital services include the treatment of depreciation, obsolescence, and changes in inventories. Chapter 8 considers measures of productivity at the level of the individual plant or company. It examines the special uses, data requirements, and other issues associated with company-level measures.

Siegel, Irving H., Productivity Measurement: An Evolving Art, Studies in Productivity: Highlights of the Literature, Study No. 16. Scarsdale, NY: Work in America Institute, Inc., 1980, 34 pp. Includes 8 pages of bibliographical references.

This publication guides the reader towards a better understanding of the field of productivity measurement by providing an overview of outstanding research, abstracts of the literature, and an extensive bibliography. The overview encompasses the development, state, and future direction of productivity measurement. It concludes that classical problems of concept, quantification, weighting, quality adjustment, deflation, and data supply persist. While improvements are still sought in the measurement of labor input, the frontiers are extended to the measurement of capital and intermediate inputs. Despite the progress made in methodology and the generation of statistics, experts remain unable to account for the recent slowdown of labor productivity growth at the national level. Finally, the value of published productivity statistics could be enhanced by a fuller awareness of their nature, limitations, actual content, and structure.

A.2 PRODUCTIVITY IN THE CONSTRUCTION INDUSTRY

Adrian, James J., and Boyer, LeRoy T., "Modeling Method-Productivity," Journal of the Construction Division, Proceedings of the American Society of Civil Engineers, Vol. 102, No. CO1 (March 1976), pp. 157-168. Includes 5 bibliographical references.

This paper focuses on the development of a productivity model that provides a typical construction firm with a means of measuring, predicting, and improving the productivity of a given construction method. Method productivity parameters are addressed by documenting productivity delays. Although the model may not recognize every construction method productivity parameter and may not always result in the development of optimal construction method productivity, it does provide the potential for local optimization for a given construction method.

Alfeld, Louis E., Research for Building Construction Productivity -- Report on the June 2, 1981 Conference, NBS-GCR-81-331. Washington, D.C.: National Bureau of Standards, August 1981, 16 pp. No references.

The conference was held to identify major research needs to improve commercial construction productivity. A consensus emerged around six primary research topics: (1) develop a "family" of micro measures of construction productivity to assist individual firms in decision-making, (2) improve macro measures of productivity to assist in understanding regional and aggregate industry trends, (3) develop the methods needed to extend computer applications to all phases of construction decision-making, (4) identify and develop methods to expedite the regulatory process, (5) measure the relationships between occupant-user productivity and building design, and (6) produce the knowledge of physical properties of buildings needed to reduce risks of building failures and lower costs of designing for building safety. Conferences further agreed that the private sector, not government, must take the initiative to formulate and conduct research. However, government should support and conduct some research.

Business Roundtable, Measuring Productivity in Construction, Construction Industry Cost Effectiveness Project Report A-1. New York: The Business Roundtable, 1982, 21 pp. Includes 11 bibliographical references.

This report reviews current construction productivity measurement procedures and proposes a program intended to provide systems for measuring productivity in construction at the aggregate industry, industry segment, and site levels, as well as to collect and disseminate construction productivity data on a national basis. The major conclusions are that greater use of site productivity measurement systems is needed, present construction statistics and aggregate productivity measurement systems are inadequate, and that existing owner/contractor data can be used to derive a series of productivity indexes that would allow owners to compare the performance of their projects with similar projects.

Cassimatis, Peter J., "Time Trends of Productivity in Construction," Chapter 6 of Economics of the Construction Industry, Studies in Business Economics No. 111. New York: National Industrial Conference Board, Inc., 1969, pp. 76-88. Includes 7 pages of bibliographical references.

This chapter is concerned with the definition of construction industry productivity measurement that can be developed from the available data, and with an evaluation of the trend in overall productivity in the construction industry. Labor productivity is measured from 1947 to 1967. The average annual increase in output per labor hour was nearly 3.0 percent during this period. This rate is well below that of most other industries and of the national economy. Total factor productivity is also measured, although less reliably because of the limitations of data, and found to have increased about 1.5 percent per year.

Cremeans, J. E., "Productivity in the Construction Industry," Construction Review, Vol. 27, No. 5 (May/June 1981), pp. 4-6. Includes 5 bibliographical references.

This article discusses a number of hypotheses that have been proposed to explain the significant decline in construction industry labor productivity in the 1970's. These hypotheses suggest that the measured decline in productivity is due to errors in the measurement or deflation of output, a decline in the capital-labor ratio, a change in the age-sex composition of the labor force, a shift towards non-union construction, an increase in government regulation, or cyclical effects. Only one of the hypotheses--the increased proportion of younger, less experienced workers--is found to be supported by the available data. The author concludes that the latest data available (1979) indicates that labor productivity in the construction industry had indeed fallen significantly and continues to fall.

Judson, Arnold S., "New Productivity Improvement Strategies for the Engineering/Construction Industry," Proceedings of the Conference on the Civil Engineer's Role in Productivity in the Construction Industry, Vol. 1. New York: American Society of Civil Engineers, 1976, pp. 49-67. No references.

The author argues that managers in the engineering/construction industry have demonstrated little capability of achieving total factor productivity improvement that is substantial and lasting. This is due to the use of traditional strategies that are no longer workable, strategies that require a top-down approach. Existing opportunities for productivity improvement in the industry are discussed, as are barriers to such productivity improvement. Desirable characteristics and examples of new productivity improvement strategies are then proposed. Examples of new approaches include productivity bargaining, quality of worklife, and continuous productivity improvement strategies. The author then explains the multi-phase process for implementing any specific new approach.

Kellogg, Joseph C.; Howell, George E.; and Taylor, Donald C., "Hierarchy Model of Construction Productivity," Journal of the Construction Division, Proceedings of the American Society of Civil Engineers, Vol. 107, No. CO1 (March 1981), pp. 137-152. Includes 1 bibliographical reference.

This paper relates the efforts of a group of construction professionals to analyze the construction industry's productivity problem, and proposes a tool for continuing analysis--the Hierarchy Model. This model addresses total factor productivity at five distinct construction industry levels: (1) policy formation; (2) program management; (3) planning/design; (4) project management/ administration; and (5) site construction. The primary role of the hierarchy model is to provide a cognitive map to solve the problem of construction industry fragmentation and a vehicle for the "total study" of total factor productivity in the industry.

Koch, Janet A. and Moavenzadeh, Fred, "Productivity and Technology in Construction," Journal of the Construction Division, Proceedings of the American Society of Civil Engineers, Vol. 105, No. CO4 (December 1979), pp. 351-366. Includes 11 bibliographical references.

This article focuses on the role of technology in the highway sector of the construction industry and its influence on productivity and price. It takes a case-study approach that entails recording the inputs required for, and influences impacting, the various tasks of production for alternative means of producing a given output. The data are used to synthesize a production isoquant for the product, which is subject to further economic analysis. The authors find that there have been substantial gains in both labor and capital productivity and efficiency in highway construction over the past 50 years in the United States, resulting in a certain offsetting of factor price increases. Nevertheless, if trends of the past are indicative of the future, then gains in efficiency can be expected to be less than previous gains. They conclude that new means of accomplishing technology change in the construction industry are clearly needed for the future.

NAHB Research Foundation, Inc., A Pilot Study on Productivity in Residential Construction. Prepared for the Department of Housing and Urban Development, Washington, D.C., July 1971, 44 pp. Includes 15 bibliographical references.

This pilot study identifies factors affecting total factor productivity in residential construction that pertain to the industry, the individual firm, and the worker. It also develops a detailed housing cost model to aid in identifying the relative amount of potential productivity gain opportunities. It then lists those factors affecting productivity that are believed to offer the important or most likely opportunities for productivity gains. Finally, three related short term studies are recommended to rank productivity gain opportunities and to define the most appropriate longer range research to lead to the achievement of both the largest and most likely productivity gains.

National Commission on Productivity and the Construction Industry Collective Bargaining Commission, Measuring Productivity in the Construction Industry (Conference Proceedings). Washington, D.C., September 14, 1972, 79 pp. Includes a few bibliographical references in footnotes.

This collection of papers from a 1972 conference includes the following works of particular interest: Mark and Ziegler, "Measuring Labor Requirements for Different Types of Construction," Behman, "Measuring Trends in Output per Manhour for Specific Craft Occupations," and Johnson, Grimm, and Thompson, "Measuring Mason Productivity." An appendix summarizes European and American studies on productivity trends in the construction industry.

National Electrical Contractors Association, Inc., and Mechanical Contractors Association of America, Inc., Effects of Job Schedule Delays on Construction Costs. Washington, D.C., August 1980, 38 pp. No references.

This 1980 survey of mechanical and electrical projects shows that significant delays in construction progress and distortions in planned schedules are not commonplace and cannot be anticipated in bids. When they do occur, they have a devastating effect on construction costs, particularly labor costs, of electrical and mechanical specialty contractors. Delay-related factors account for nearly 90 percent of the total labor cost overrun experienced by these contractors on projects with schedule problems. Contractors report that the most significant effects of schedule problems are related to productivity of the work force. Loss of momentum and productive rhythm is the greatest of these effects, followed by the need for redundant mobilization and demobilization in various job areas, and by demoralization of employees.

Rosefielde, Steven and Mills, Daniel Quinn, "Is Construction Technologically Stagnant?," in The Construction Industry: The Balance Wheel of the Economy (edited by Julian E. Lange and Daniel Quinn Mills). Lexington, MA: Lexington Books, D.C. Heath and Company, 1979, pp. 83-111. Includes 3 pages of bibliographical references in footnotes.

Government statistics suggest that the construction industry is technologically stagnant. They seem to show a slow rate of productivity growth, rapid cost inflation, and limited growth in the industry's output. This chapter analyses these statistics by examining the definitions used in compiling them, the ways in which statistics are collected, and their tecchnical meaning. The analysis shows that construction is not a technologically stagnant sector of the economy, but one characterized by continuous and large-scale change. Yet these changes, generally of a socially beneficial nature, result in low measured rates of advance in labor productivity and actual decreases in capital productivity.

Ruff, Edwin R. (Ed.). Proceedings of the Conference on Construction Productivity Improvement. Austin, TX: Department of Civil Engineering, University of Texas at Austin, 1980. No references

Session III of this conference is devoted to methods of productivity measurement that are applicable to the construction site. One paper discusses unit cost analysis as a method of controlling field labor productivity. Other field methods discussed in this session include work sampling, craftsmen questionnaires, and foreman delay surveys.

Stokes, H. Kemble, Jr., "An Examination of the Productivity Decline in the Construction Industry," The Review of Economics and Statistics, Vol. 63, No. 4 (November 1981), pp. 495-502. Includes 10 bibliographical references.

Labor productivity in the construction industry increased annually by 2.4 percent between 1950 and 1968, but between 1968 and 1978 labor productivity declined annually by 2.8 percent. This article addresses seven possible explanations for these trends in construction industry labor productivity: (1) the measurement of real output, (2) shifts in the composition of construction industry output, (3) changes in capital per worker, (4) demographic changes in the workforce, (5) economies of scale, (6) regional shifts, and (7) changes in work rules or practices. The results indicate that only 25 percent of the deterioration in labor productivity is explained by these factors. The major contributing factor has been the slower growth in capital per worker. While other factors make a contribution to explaining recent productivity trends, the magnitudes are very small. There has been much speculation in the literature that the productivity problem was merely a measurement problem, that real output was understated, but no conclusive evidence was found to support that hypothesis. The labor productivity declines in the construction industry during the past decade are real.

Thompson, Bruce E. and Chapman, Robert E., Productivity in Residential Construction: An Annotated Bibliography, NBSIR 80-2150. Washington, D.C.: National Bureau of Standards, February 1981, 52 pp.

This report presents a state-of-the-art review of the technical literature related to one or more of the factors affecting productivity in residential construction. Particular emphasis is placed on identifying potential sources of variation between the level of productivity in new housing construction versus that in housing renovation. Although this report focuses on the residential sector, emphasis is also placed on topics such as construction management and cost control which apply even to a greater extent to the nonresidential residential sector. The references have been categorized so that articles dealing with specific productivity and construction topics can be easily identified. The categories emphasized in this report are: general productivity/productivity measurement; construction productivity; residential rehabilitation/renovation; construction/housing costs; construction cost estimation and control; economics of construction; and building codes and regulations.

Woodhead, W. D., "Productivity Factors in System Housing." Commonwealth Scientific and Industrial Research Organization, Division of Building Research, Melbourne, Australia, 1979. Includes 7 bibliographical references.

This monograph reports on research which measured labor requirements per square meter for eight alternative designs of single-family housing in Australia. Three of the designs were conventional and five were innovative. The data were derived from on-site observations. Labor requirement data are provided for the entire building on a gross and net floor area basis, as well as for selected building systems. The determinants of variations in labor requirements are also discussed.

A.3 PRODUCTIVITY MEASUREMENT CASE STUDIES

Adam, Nabil R. and Dogramaci, Ali, eds., Productivity Analysis at the Organizational Level, Studies in Productivity Analysis, Volume III. Boston: Martinus Nijhoff Publishing, 1981, 181 pp. Includes bibliographical references after each chapter.

This is a collection of original papers on productivity analysis at the organizational level. The book is divided into three parts: perspectives on productivity measurement, a range of studies at the micro level, and some productivity issues in public organizations. The first two parts are useful to those interested in private sector, firm-level productivity measures. The first chapter in part I discusses different methods for constructing partial productivity ratio measures, as well as alternative methods of measuring a given choice of inputs and outputs. Also presented in this chapter is a brief history of company-based productivity studies that go back to the turn of the century. The next chapter discusses a number of problems in the measurement of labor inputs, capital inputs, and outputs. Part I ends with an example of labor and total factor productivity measurement for a specific industry (food retailing). Part II begins with a chapter that develops a set of models to analyze the complex interrelationships between a multitude of labor productivity components. The next chapter provides an algorithm to solve an operations research problem in the area of human resources and labor productivity. Another chapter develops the design of an experiment for productivity-related ratio analysis in an organization. Finally, the last two chapters of part II deal with issues related to industrial economics and address the question of whether larger firms tend to have higher labor productivity.

Bailey, David and Hubert, Tony (Eds.). Productivity Measurement: An International Review of Concepts, Techniques, Programmes, and Current Issues. Westmead, U.K.: Gower Publishing Company Limited, 1980. No references.

The papers published in this volume were originally presented in 1979 at one of a series of conferences sponsored by the European Association of National Productivity Centres. The major focus of these papers is on productivity measurement at the level of the firm. The approaches discussed include financial ratios, labor productivity, and a new method called resource allocation strategist (REALST) which measures the contributions to profit variance of differences in capacity utilization, efficiency, and resource costs. A number of inter-firm case studies are presented from various countries.

Cocks, Douglas L., "The Measurement of Total Factor Productivity for a Large U.S. Manufacturing Corporation," Business Economics (September 1974), pp. 7-20. Includes 16 bibliographical references in footnotes.

This article outlines a specific methodology for the measurement of total factor productivity for an individual firm that allows a direct comparison with all U.S. nonfinancial manufacturing corporations. The methodology is based on a study completed by the U.S. Department of Commerce, Bureau of Economic Analysis (see subsection A.1--John A. Gorman). This methodology is applied to a large, fairly diversified U.S. manufacturer--Eli Lilly and Company. Then an approach for treating research and development as a capital input is presented. The author finds that this alternative treatment of research and development as a capital input has virtually no effect on Lilly's total factor productivity measure.

Craig, Charles E. and Harris, R. Clark, "Total Productivity Measurement at the Firm Level," Sloan Management Review, Vol. 14, No. 3 (Spring 1973), pp. 13-29. Includes 6 bibliographical references.

This article describes a theoretical framework for firm-level productivity measurement that is particularly suitable for supporting the corporate management decision process. The model is described as a service flow model. Physical inputs are converted to dollar equivalents which are remunerations for services provided by those inputs. The return to capital is the residual left when all other input factors have been paid for their services. This method differs from others in its treatment of capital and the use of all inputs and outputs. A lease service concept of capital is used rather than a physical consumption concept. Also, all revenue items are included as outputs and all cost or expense items are inputs. A case study from the manufacturing industry is used to demonstrate the method and to point out some of the difficulties in making the actual calculations.

Eilon, Samuel; Gold, Bela; and Soesan, Judith, Applied Productivity Analysis for Industry. Elmsford, NY: Pergamon Press, Inc., 1976, 151 pp. Includes bibliographical references after each chapter.

This book is divided into three parts. The first part is devoted to a discussion of the current concept of productivity and its definitions, and to a literature survey of various prevailing approaches to the problem. It then proceeds to propose a framework for productivity analysis and an array of management-control ratios and also to indicate how problems of measurement can be overcome in practical situations. The second part describes five case studies from the manufacturing industry to illustrate how the proposed methodology can be applied in various situations involving different levels of complexity and aggregation. In the third part, various problems encountered during the case studies in measurement and analysis are reviewed and suggestions are made as to how they can be overcome. Then the use of the model for planning purposes is discussed through sensitivity tables, deterministic appraisals, and risk simulation. The concluding chapter suggests that the methodology employed in this book can be applied to various industries.

Greenberg, Leon, A Practical Guide to Productivity Measurement. Washington, D.C.: The Bureau of National Affairs, Inc., 1973, 71 pp. Includes 15 bibliographical references.

This guide to company productivity measurement is directed primarily to the company manager. It concentrates on the measurement of labor productivity trends, dealing with other types of measures and the measurement of levels of productivity only briefly. It begins with simple types of production and moves through more complex production simulations. Examples are given to illustrate the methods of calculation. Guidelines are offered for measuring productivity in service industries. Government productivity statistics for the economy, major industry sectors, and individual industries are also discussed.

Hines, William W., "Guidelines for Implementing Productivity Measurement," Industrial Engineering, (June 1976), pp. 40-43. Includes 9 bibliographical references.

This paper presents a brief review of productivity measurement methods and case studies at the level of the firm. Specific measurement problems are discussed and guidelines are presented for industrial engineers to implement a regular program of total factor productivity measurement for their companies.

Katzell, Raymond A.; Bienstock, Penney and Raerstein, Paul H., A Guide to Worker Productivity Experiments in the United States, 1971-1975, prepared for Work in America Institute, Inc. New York: New York University Press, 1977, 186 pp. Includes an annotated bibliography of 103 references.

In this book, three psychologists summarize and analyze 103 case studies designed to improve the productivity of workers. The experiments under review were performed in the United States and reported in publications issued from 1971 through 1975. Although based predominantly on experience in business and industry, nearly one third of the case studies were performed in nonprofit agencies, and the case studies involve workers from a wide range of occupations and levels. This literature indicates that the improvement of worker performance is attainable through strategies already within our grasp. The limitations of many of the experiments, however, raise questions about the validity or generalizability of their findings.

Kendrick, John W. and Creamer, Daniel, Measuring Company Productivity: Handbook with Case Studies, Studies in Business Economics, No. 89, New York: National Industrial Conference Board, Inc., 1965, 120 pp. Includes 11 bibliographical references.

This report discusses the value of company productivity measures and the technical difficulties that are involved in the estimating procedures. The first chapter, which is designed primarily for the general executive, presents the meaning and uses of company measures of productivity. The body of the report is devoted to the problems and procedures of estimating. A section of case studies follows which shows how six major companies have measured company productivity. The case studies include two uses of labor productivity measures--"Measuring Labor Productivity in the General Oil Company: and "Measuring Labor Productivity by Sub-components"--and four uses of total productivity measures--"Measuring Labor and Capital Productivity: A Short-cut Method," "Measuring Total Productivity at the Divisional Level of and Equipment Manufacturer," "Total Productivity Measurement at the Midwest Manufacturing Company," and "Total Factor Productivity Measure at a Durable Goods Manufacturing Company." These cases are meant to demonstrate that such measures can be implemented in practice.

Kraus, Jerome, "Productivity and Profit Models of the Firm," Business Economics, Vol. 13, No. 4 (September 1978), pp. 10-14. Includes 5 bibliographical references in footnotes.

This paper presents a model for forecasting profits of a firm based on a modified income statement and the use of single factor productivity measures. The major modification is to convert the bottom line of the traditional income statement (i.e., income after taxes) into an appropriate measure of firm output, such as sales adjusted for inventory change. The purpose of the model is to permit the forecasting of profits to be based on economic variables, such as prices, sales volume, and productivity.

Litton Systems, Inc., Productivity Measurement Model Users Manual, Report No. PRR-70-2. Prepared for Department of the Navy, Bureau of Naval Personnel, Washington, D.C., July 15, 1969, 31 pp. No references.

This users' manual provides operating instructions, definitions, assumptions, and computer program documentation for the Productivity Measurement Model (PMM). The PPM computes productivity indices for large, decentralized industrial organizations. Specifically, the model develops comparable labor productivity measures for both lower and higher organizational levels. Then aggregate productivity indices for the entire organization are formed by a weighted average process.

Nadiri, M. Ishaq, and Schankerman, M. A., "The Structure of Production, Technological Change, and the Rate of Growth of Total Factor Productivity in the U.S. Bell System," in Productivity Measurement in Regulated Industries (edited by Thomas G. Cowing and Rodney E. Stevenson). New York: Academic Press, 1981, pp. 219-247. The book includes 13 pages of bibliographical references.

The objectives of this preliminary study are threefold. The first is to analyze empirically the production structure of the Bell System at the aggregate level. Particular attention is focused on the pattern of substitution among the factor inputs and the degree to which the aggregate production function is characterized by economics of scale. In this connection, the authors explore the role of research and development in the Bell System as an input in the production process, and its interaction with the traditional inputs. Second, they examine the impact of external technological change on the production structure of the Bell System. The issues here include not only the rate of such change, but also its factor bias. The third objective is to explore the interrelationships between economies internal to the Bell System and external technical change in determining the rate of growth of total factor productivity (TFP). Specifically, the authors propose and illustrate a methodology for decomposing the observed growth of TFP into a part related to scale economies and a part induced by technical change. These three objectives are addressed by first estimating an aggregate translog cost function for the Bell System, using annual data for the period 1947-1976. The implied estimate of scale economies is then used to explore the sources of TFP growth.

Siegel, Irving H., Company Productivity: Measurement for Improvement. Kalamazoo, Michigan: W.E. Upjohn Institute for Employment Research, 1980, 88 pp. Includes bibliographical references in footnotes.

The purpose of this book is to assist managers in tracking their company's productivity over time. Chapters deal with the benefits of measuring company productivity, definitions of productivity, and methods for establishing a company measurement program. The final chapter offers some examples of company productivity measurement. The examples cover both single and total factor productivity. An appendix summarizes a number of productivity measurement methods.

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11. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)*

The fundamental concept underlying all productivity measures is a comparison of the output of a production process, an enterprise, an industry, or an economy with the corresponding factors of production (inputs) required to generate that output. Productivity measures are formulated as a ratio of output to one or more of the inputs. This report evaluates alternative productivity measures and concludes that the comprehensive Total Factor Productivity (TFP) method is preferred to the Single Factor Productivity method. To combine the multiple components in the denominator of a TFP index, a weighting system based on relative factor cost shares is recommended. A measurable index of the instantaneous rate of change in TFP between two time periods is derived from a general production function. The report also investigates the specific data requirements for implementing this TFP measure in the construction industry. An annotated bibliography is included.

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