Manufacturing multifactor productivity in three countries

Multifactor productivity growth in the United States has been lower than the growth rates recorded by Germany and France since 1956, but only the U.S. rates show a pickup since the post–1973 slowdown

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In a comparison of manufacturing multifactor productivity between three G-7 countries over the 1956–93 period, the largest average annual rate of increase, 3.1 percent, occurred in France. Germany followed at 2.3 percent and the United States with 2.1 percent.

After 1973, the growth rates slowed in all three countries. The rate in the United States picked up in the 1979–93 period, but evidence of such a recovery in Germany and France remains to be seen. Because manufacturing multifactor productivity is strongly affected by the business cycle, observers must wait for cyclical disturbances to subside in those countries for a more definite answer.

Labor hours in U.S. manufacturing rose slightly over the full period studied; they declined significantly in Germany and France, particularly after 1973. At the same time, capital services inputs were increasing steadily in all three countries. The result was an overall substitution of capital for labor, which was especially vigorous in Germany and France before 1973, and intensifying in the United States after 1973.

Over the period 1956–93, labor productivity increased faster in Germany and France than in the United States over this period because of much larger average increases between 1956 and 1979. But in the more recent 1979–93 period the United States had the highest average annual labor productivity growth rate. German and French growth rates were higher before 1973, due mostly to a more rapid substitution of capital for labor. Following 1973, the rates of substitution became more similar; differences in manufacturing multifactor productivity changes decided the leadership in labor productivity growth, often on a cyclical basis.

Multifactor productivity differs from the traditional measure of labor productivity by explicitly including capital as a factor of production. Including capital as an additional input not only recognizes its importance as a factor of production, but also makes it possible to analyze and explain how other factors influence labor productivity.

For many years, the Bureau of Labor Statistics has compared manufacturing labor productivity among the United States and many of its industrialized economic competitors. Likewise, for more than a decade, BLS has published multifactor productivity measures for U.S. manufacturing industries and other broad sectors of the U.S. economy. Now, BLS is applying similar techniques to productivity trends in various countries, providing a new tool to understand what shapes international competitiveness and why labor productivity trends differ among countries. Comparisons in this article between the United States and two other G-7 countries, Germany and France, are the beginning of a wider project that will eventually include other industrial economies.

The basic approach of this study follows the methodology developed by BLS to measure multifactor productivity for broad sectors of the U.S. economy.[1] The study considers the aggregate manufacturing sector, without an analysis of developments in individual manufacturing indus-

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tries. This follows the approach of BLS international labor productivity comparisons in which the aggregate manufacturing sector is, with some exceptions, the unit of analysis.

Methodology

The multifactor productivity measures in this study are based on a generalized production function for a country's manufacturing sector, and are estimated from the following relationship:[2]

$$(1)\quad ln\left(\frac{MFP_t}{MFP_{t-1}}\right) = ln\left(\frac{GPO_t}{GPO_{t-1}}\right) - \frac{1}{2}(w_{l,t-1} + w_{l,t}) \times ln\left(\frac{L_t}{L_{t-1}}\right) - \frac{1}{2}(w_{k,t-1} + w_{k,t}) \times ln\left(\frac{K_t}{K_{t-1}}\right)$$

where *MFP* = multifactor productivity
- *GPO* = the real gross product originating (or value added) in manufacturing
- *L* = input of labor services
- *K* = input of capital services
- w_l = labor's share of current price value added
- w_k = capital's share of current price value added

An assumption underlying the weights (w_l and w_k) used in this model is that the two primary factors of production, labor and capital, divide all the value added between themselves, each being paid the value of its marginal contribution to output (its marginal product). This implies competitive markets for the factors of production. Multifactor productivity is a residual that registers those changes in the sector's real output (GPO), which are not due to variations in labor and capital inputs. This would include technological changes, gains in organizational efficiency, changes in the skill composition of labor input, and the benefits from research and development. The multifactor productivity measures and comparisons presented in this article are in the form of indexes or percent changes, and no level comparisons are made. An alternative, the dual formulation of equation 1, is shown in the appendix.

Defining manufacturing. The definition of manufacturing is not identical among the United States, Germany, and France. The German definition differs from the United States in that it includes some quarrying and also the repair of electrical equipment for households, and the repair of motor vehicles, railroad equipment, and tires, which are classified in the industries that produce these products. Data for Germany apply to the former West Germany.[3] The French data apply to mining and manufacturing less energy-related products. As a result, the French definition excludes petroleum refining and includes the quarrying and mining of nonenergy-related products. The processing of agricultural products and foodstuffs is added to the manufacturing sector as defined in the French national statistics, which excludes these industries.

Manufacturing output. Real (deflated) gross product originating in manufacturing (value added) is the output measure for each of the three countries. Another possible output measure is discussed in the appendix. However, price-base years used to measure real output and the frequency and methods of changing price weights, which can lead to differences in real output growth rates, are different among the three countries.

Until the 1990's the U.S. national accounts were only deflated using fixed weights, that is the prices in a particular year. In this method the base year is changed every 5 years, but the new base prices are then applied to the entire time series, so that data for all previous years are deflated using the price structure of the most recent benchmark year. The result is that the growth in real output for years before the benchmark year is generally underestimated. This is still the featured measure of U.S. output, but the Commerce Department's Bureau of Economic Analysis also computes and publishes alternate output measures, including a benchmark-years-weighted measure of manufacturing real output.[4]

This deflation method uses the Fisher Ideal Index formula and weights from two benchmark years, customarily 5 years apart. For each pair of adjacent benchmark years, the weights are computed as the geometric mean of fixed-weighted quantity indexes based on each of the two benchmark years.[5] These measures share one important characteristic with the output measures computed for German and French manufacturing: the two Nations use different weights for different periods, rather than using the same fixed-weighted structure for all years.

However, the benchmark-years-weighted measures also have some limits. The benchmark years correspond to the years for which Census of Manufactures data are available, and relative prices in these years may be affected by cyclical factors that are less relevant to other years. In addition, the current BEA benchmark-years-weighted measures of manufacturing output have not been applied before 1977 and end with the latest benchmark in 1987; the data for subsequent years use constant 1987 weights.

Therefore, a chain-type annual-weighted index developed by BLS is being used. This index is compiled by means of a Törnqvist aggregation of deflated output values for detailed manufacturing industries, using moving weights. The index is based on the assumption that changes in gross output are equal to the sum of weighted changes in intermediate inputs and changes in value added. The latter can be obtained as a residual. The change in the gross output of an industry is

$$(2)\quad d\ln(Y_i) = \bar{w}_{x,i} \times d\ln(X_i) + \bar{w}_{GPO_i} \times d\ln(GPO_i)$$

where Y_i is real gross output of industry i, X_i are real intermediate inputs to industry i, and w_x and w_{GPO} are the share weights of intermediate inputs and of value added in the value of production. Then the change in real GPO (net output) is

$$(3)\qquad d\ln(GPO_i) = \frac{\left[d\ln(Y_i) - \bar{w}_{x,i} \times d\ln(X_i)\right]}{\bar{w}_{GPO_i}}$$

and the change in total manufacturing GPO is obtained as an aggregate:

$$(4)\qquad d\ln(GPO) = \sum_i \bar{w}_i \times d\ln(GPO_i)$$

In all cases, weights are taken from the two years over which growth is being measured. Lastly, the annual GPO growth rates are chained into the index shown.

This index is currently available for years up to 1992. The 1993 value was estimated based on the trend shown by the industrial production index published by the U.S. Federal Reserve Board. The manufacturing output series calculated by the annual-weighted method results in faster annual growth rates before the benchmark year than would have been obtained if fixed weights had been used. The following tabulation shows the average annual rates of increase in manufacturing output over 1979–87 based on the three methods:

1987 fixed-price weights	1.5 percent
Benchmark-years-weighted	2.3 percent
Annual-chain-weighted index	3.1 percent

German manufacturing output is real product originating in manufacturing, as reported in the national accounts regularly published by the German national statistical office, *Statistisches Bundesamt*. Germany normally introduces new price weights every 5 years. This price structure is used for the preceding 5 to 10 years. For earlier years, this price structure is used at the level of detail published, but the old price structure is maintained at a finer level of detail.

For France, output is real GPO for the sectors here defined as manufacturing, as reported in the national accounts by the national statistical institute, the Institut National de la Statistique et des Etudes Economiques (INSEE). In the French national accounts, alternative series are published, one using transactions valued at the prices of the previous year and the other using transactions valued at the prices of a base year. The base year is normally changed every 10 years, and series on the different base years are linked. The measures used for this article are the base-year linked measures.[6]

Labor input. Labor input is defined in this article as total hours worked by all persons active in the manufacturing sector. This includes the self-employed and unpaid family workers as well as employees (wage and salary workers). Labor input is not distinguished by categories such as experience, age, or gender, and no quality differentiation is assumed. The labor input data are the same as those used in the international comparisons of labor productivity computed by BLS.

Labor compensation is used to calculate labor's share in total value added (w_l in equation 1). This includes direct payments (wages and salaries, paid vacations, bonuses, payments in kind) and indirect payments (employer contributions to social insurance, health, and pension benefits). The data on employee compensation are from national accounts sources.[7] The compensation of self-employed persons is estimated by assuming that the hourly compensation costs of the self-employed are the same as for employees.

Capital inputs. Capital inputs to the production process are defined as the value of services per year from stocks of productive capital assets, both stocks and services valued in real terms. Capital service flows are assumed to be proportional to the capital stock. Consequently, the measurement of capital inputs depends on the proper calculation of the capital stock level, at constant prices. Capital used in manufacturing comes in many forms and categories, although these can be summarized in the four broad classes of fixed business equipment (including vehicles), structures, inventories, and land. The various types of capital stock are combined into an aggregate capital stock index by applying appropriate weights in a Törnqvist formula

$$(5)\qquad \ln\left(\frac{K_t}{K_{t-1}}\right) = \sum_i \tfrac{1}{2}\left(s_{i,t-1} + s_{i,t}\right) \ln\left(\frac{K_{i,t}}{K_{i,t-1}}\right)$$

K_t = the real, weighted aggregate value of all asset categories in year t.
$K_{i,t}$ = the real value of capital asset category i in year t,
$s_{i,t}$ = the weights used in combining the capital categories.

Taking an approach similar to that used in equation 1 and making related assumptions, the weight $s_{i,t}$ of each asset category i is set equal to the asset's estimated share of total capital income in year t. Assuming competitive markets for the different categories of capital, each category receives a rent equal to its contribution. And if Y_t denotes the total income to capital, and $c_{i,t}$ the rent earned by a unit of capital in category i, then

$$(6) \quad s_{i,t} = \frac{K_{i,t} \times c_{i,t}}{Y_t} \quad \text{and} \quad Y_t = \sum_i K_{i,t} \times c_{i,t}$$

Generally, published data series are not available for $K_{i,t}$ and $c_{i,t}$, the stocks of the different types of capital and of the income that they earn. Therefore, both variables must be estimated.

The capital stock levels of depreciable fixed assets are estimated by applying the *perpetual inventory method* (PIM), which consists of cumulating past *investments* in each type of asset, while making due allowances for the decline in efficiency that accompanied the aging of assets, which ultimately are scrapped. The BLS method assumes that efficiency declines gradually early in an asset's life and more quickly later. Space limits permit only a very compressed description of the PIM method used at BLS. This is presented in the appendix, where the effect of assumed asset service lives on capital service inputs also is examined. Other sources and methods are used to estimate the stock levels of the nondepreciating assets, inventories and land, as is indicated below.

Rental prices $c_{i,t}$ are estimated by an imputed rent formula, which calculates what each asset would earn if it could be rented in a competitive market for capital assets. The imputed rent formula requires data series on asset prices, income and property tax rates, and asset depreciation.[8] (See the appendix for more details about the rental price formula.)

Theoretical considerations suggest that when applying formula 5, the different types of asset categories should be combined at as disaggregated a level as possible. The more categories, the more homogeneous will be the assets that comprise each category; as a result, the more accurate will be the overall index (K_t). For the United States, BLS aggregates up to 25 types of capital assets for each of 20 manufacturing industries (that is, formula 5 is applied industry by industry). Investment data by asset type and by industry are obtained from BEA. The capital input series for U.S. manufacturing, used in the present study, is a summation of the real aggregate capital input values across all manufacturing industries.

For Germany and France, capital estimates are available for only four asset categories: equipment, structures, inventories, and land. Investment series for equipment and structures in German manufacturing, and for inventory levels, are provided by national account statistics. For France, the published national accounts provide only total fixed investments in manufacturing. The breakdown into equipment and structures was provided by the French statistical institute, INSEE. French manufacturing inventories are estimated from annual changes in inventories. None of the three countries being compared publishes data for land used in manufacturing. In all three cases, the value of land is estimated by applying a land/structures ratio to the estimated stock of structures.

The time periods

When comparing differences in manufacturing output and productivity trends among different countries, care should be taken that these trends not be unduly affected by cyclical fluctuations. Productivity measures tend to reflect these cyclical movements, because output (the numerator) is very sensitive to changed demand conditions, while factor inputs (the denominator) are more sluggish. A common way to remove such effects is to measure changes only between years that correspond to similar cyclical phases, preferably cycle peaks.

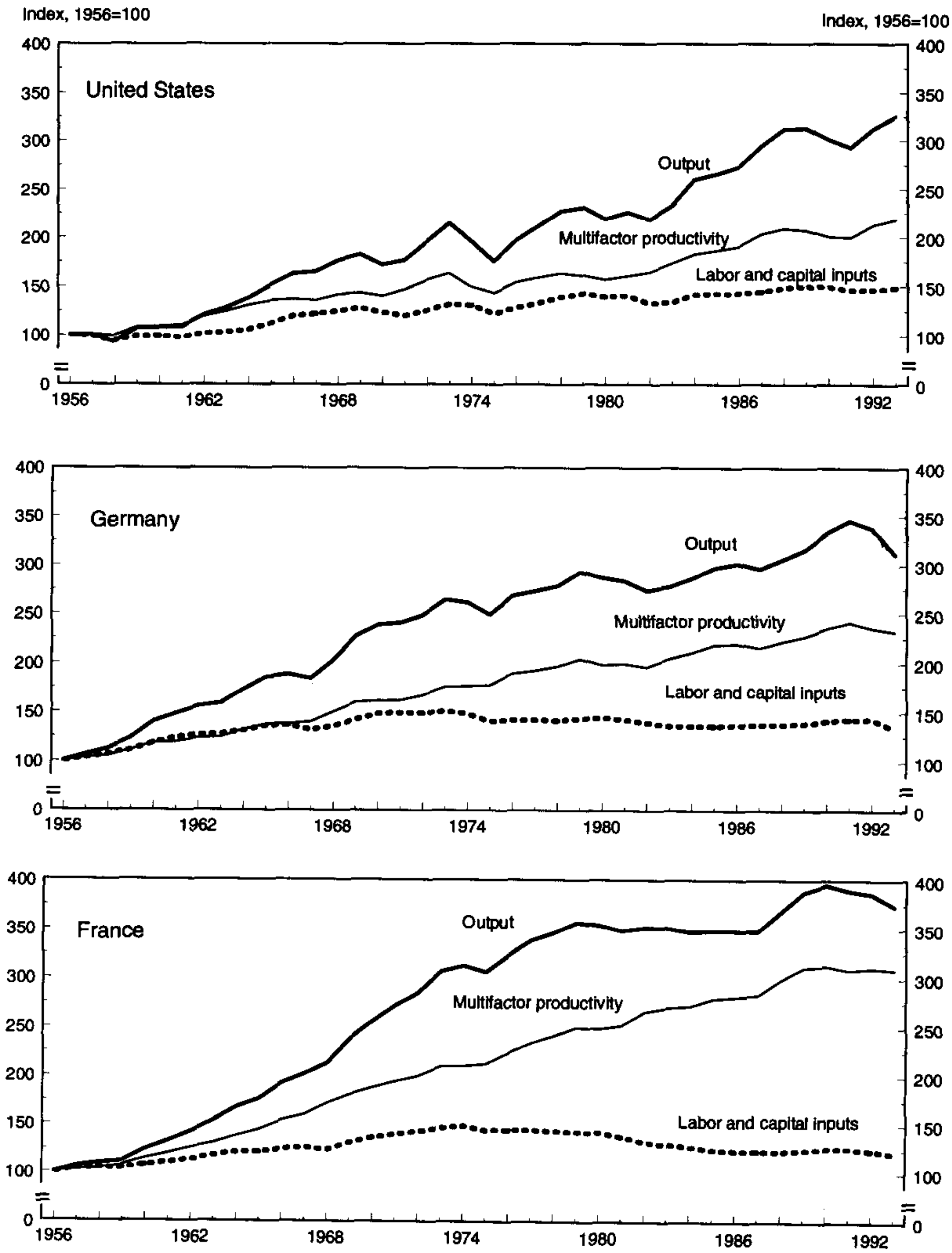
For the United States, during the years covered by this study (1956–93), seven reference cycle peaks, certified by the National Bureau of Economic Research (NBER) business cycle dating committee, have occurred. Without imitating the elaborate timing methods used by the NBER, we will define a local cycle peak in manufacturing output as a year with positive or zero growth in real manufacturing GPO that precedes a year with negative growth in real GPO. According to this definition, U.S. manufacturing peaks generally coincided with or slightly led all U.S. reference cycle peaks, with the exception of the mild recession of 1960–61, when manufacturing output continued to grow.

The terminal years used for analysis in this study are 1956, 1973, 1979, 1990, and the most current year, 1993. Besides being local maxima output years in the United States, 1973 and 1979 also stand out because they were the beginning years of the first and second energy crises and because of the severity of the following recessions. German manufacturing output hit peaks during the same two years. In France, manufacturing output peaks occurred in 1974 and 1979, but growth slowed substantially in 1973. For these reasons, 1973 and 1979 were selected as two of the years that would anchor periods of comparison in the present study. Manufacturing productivity measures are available for all three countries beginning in 1956. Manufacturing output in the United States peaked in 1957, while the German and French manufacturing sectors were growing strongly at that time and did not hit cyclical peaks until 1966 and 1974. Therefore, it does not appear that 1956 output was influenced by cyclical movements in any of the three countries.

On an annual average basis, U.S. manufacturing output peaked again in 1989, German output in 1991, and French output in 1990. Since U.S. manufacturing output peaked in the third quarter of 1990 and German output was rising strongly in 1990 and 1991, 1990 was selected as another terminal year for analysis.

The fifth pivot year, 1993, is more of a problem. It is the most current year for which the comparisons are available,

Chart 1. **Manufacturing output, labor and capital inputs, and multifactor productivity, 1956–93**



but it hit the United States and the two European countries at very different cyclical stages. For the United States the problem is less severe, because manufacturing output hit its last low in 1991; by the end of 1993 a large proportion of the cyclical recovery should have taken place. However, German and French manufacturing output were still falling from their peaks in 1991 and 1990; as of 1993 they were moving in the opposite cyclical direction from the United States.

Productivity measures for periods ending in 1993 reflect the facts as we know them from the latest available information, and are therefore important. As data arrive for 1994 and later, the results will be recorded. Given these facts, one should not accept as definitive international productivity comparisons that have 1993 as the ending year. In the summary comparative tables, average rates of change are shown for 1956–90 and 1956–93.

Trends, by country

Because Germany and France had not, as of 1993, recovered from their cyclical downturns, much of the analysis concentrates on the period ending in 1990.

United States. Manufacturing *multifactor productivity* registered an average annual increase of 2.1 percent the entire 1956–93 period. (See table 1). Growth declined from an average of 2.9 percent annually before 1973 to 1.2 percent between 1973 and 1990. However, this slower multifactor productivity growth was composed of an annual decline of 0.2 percent during 1973–79 (when labor and capital inputs grew faster than output), followed by a recovery to 2.0 percent annually in 1979–90 and 2.8 percent a year during 1990–93.

While the average rate of increase since 1973 is clearly below the pre-1973 average growth rate, one cannot conclude on the basis of this evidence alone that there has been a fundamental shift—a decline—in productivity growth after 1973. While the fastest increase in manufacturing multifactor productivity occurred during 1956–73 (2.9 percent annually), it increased nearly as fast during 1990-93 (2.8 percent annually) and has averaged 2.2 percent annually since 1979. It could be argued that the 1973–79 period, characterized by the first energy crisis and the measures taken by industry to adapt to it, was atypical. By treating the 1973–79 data as outliers–observations that vary abnormally from statistical averages—U.S. multifactor productivity may be back on a growth trend similar to—though somewhat less rapid than–the trend of the pre-1973 years.

Multifactor productivity trends can be explained by relative changes in manufacturing output and factor input growth rates. U.S. manufacturing *output* (real gross product originating) grew at a 3.3-percent annual average during the 1956–90 period, with slowdowns and declines during cyclical re-

Table 1. **Growth rates of manufacturing output, factor inputs, and productivity, U.S., Germany, and France, selected periods, 1956–93**

[Average annual percent changes]

	Output			Labor input		
	United States	Germany	France	United States	Germany	France
1956–90	3.3	3.6	4.1	0.3	−1.0	−0.8
1956–93	3.2	3.1	3.6	.1	−1.2	−1.0
1956–73	4.6	5.9	6.8	.8	−.6	.5
1973–90	2.0	1.4	1.5	−.3	−1.4	−2.1
1973–79	1.2	1.7	2.6	.4	−2.5	−1.8
1979–90	2.5	1.2	1.0	−.7	−.9	−2.2
1990–93	2.6	−2.2	−1.8	−1.3	−3.3	−3.0
	Capital services			**Labor and capital input**		
	United States	Germany	France	United States	Germany	France
1956–90	3.9	4.7	4.6	1.2	1.0	.7
1956–93	3.8	4.5	4.3	1.1	.8	.5
1956–73	3.9	7.4	6.6	1.6	2.4	2.3
1973–90	4.0	2.0	2.6	.8	−.4	−.9
1973–79	4.5	2.5	3.5	1.4	−.8	−.4
1979–90	3.7	1.8	2.0	.4	−.1	−1.1
1990–93	2.6	2.4	1.8	−.2	−1.8	−1.4
	Capital services per hour			**Output per hour**		
	United States	Germany	France	United States	Germany	France
1956–90	3.7	5.8	5.4	3.0	4.7	5.0
1956–93	3.7	5.8	5.4	3.1	4.4	4.6
1956–73	3.0	8.1	6.1	3.8	6.5	6.3
1973–90	4.3	3.5	4.7	2.3	2.9	3.7
1973–79	4.2	5.1	5.5	0.8	4.3	4.5
1979–90	4.3	2.7	4.3	3.1	2.1	3.2
1990–93	3.9	5.9	5.0	4.0	1.2	1.2
	Output per unit of capital services			**Multifactor productivity**		
	United States	Germany	France	United States	Germany	France
1956–90	−0.6	−1.1	−0.4	2.1	2.6	3.4
1956–93	−.6	−1.3	−.7	2.1	2.3	3.1
1956–73	.7	−1.5	.2	2.9	3.4	4.4
1973–90	−1.9	−.7	−1.0	1.2	1.8	2.4
1973–79	−3.2	−.8	−.9	−.2	2.6	3.0
1979–90	−1.2	−.6	−1.1	2.0	1.3	2.1
1990–93	.1	−4.5	−3.6	2.8	−.4	−.4

cessions. Growth was more than twice as fast during 1956–73 (4.6 percent annually) than in 1973–90 (2.0 percent). There was a significant drop in output from the 1973 peak to the 1975 trough (–18.3 percent), marking the post-1973 energy crisis and recession, and overall growth was very slow in the 1973–79 period. However, after 1979, real output growth picked up again, to an average annual rate of 2.5 percent during 1979–90 and 2.6 percent during 1990–93.

On the input side, total *hours worked* grew slowly for the period—only 0.1 percent annually during 1956–93. Labor input increased overall during 1956–79, with very rapid increases during the 1950's and 1960's, and a decline since then. Labor hours rose slightly during 1973–79, then declined during the post-1979 period; the pace of the decline accelerated after 1990. Hours worked in 1993 were 10.6 percent below their peak in 1979, but were 5 percent above their 1956 value.

Capital service inputs grew vigorously and fairly steadily throughout the 1956–90 period, with no recorded annual declines. This is true even for recession years.[9] For U.S. manufacturing, the rate of capital input growth varied relatively little among the different time periods between 1956 and 1990, from a high of 4.5 percent annually during 1973–79 to a low of 3.7 percent annually during 1979–90. However, capital service inputs rose only 2.6 percent annually in 1990–93. What is unusual (compared with the other countries) is that capital inputs increased as rapidly after 1973 as before 1973. It should be noted that the most rapid growth in capital service inputs occurred during the 1973–79 period, which was marked by the first energy crisis, as U.S. manufacturers adjusted to increasing energy and labor costs.

The *combined labor and capital inputs* resulted in a generally rising trend throughout the 1956–90 period. The increase was most rapid before 1973, at an annual average of 1.6 percent, and lowest between 1979 and 1990, at 0.4 percent per year, because of the decline in labor inputs. The only negative average occurred during 1990–93, because of a significant drop in labor hours and smaller increases in capital services inputs.

There was an overall substitution of capital for labor as capital service inputs increased faster than labor hours. This is shown by the *capital services/hours worked* ratio, which grew an average of 3.7 percent per year between 1956 and 1990. The ratio grew somewhat faster during the post–1973 period (4.3 percent annually), but in general, this rate of substitution was quite stable throughout the entire 37 years. In this aspect, the United States differs from Germany and France, where the substitution of capital for labor in manufacturing proceeded at a faster rate over the entire 1956–93 period. However, the increases were front-loaded on the earlier, pre-1973 period, with significantly slower substitution in the more recent years.

Finally, the trends in *capital productivity*, defined as the ratio of *output per unit of capital service inputs*, also should be noted. The steady growth in capital inputs, and the substitution of capital for labor, resulted in an overall decline in this ratio. The 1956–73 period was an exception, with a small average increase of 0.7 percent annually. The decline in capital productivity since 1973, particularly prominent in 1973–79 (-3.2 percent annually), resulted from rapid increases in capital service inputs during a period of relatively slow manufacturing output growth. Relative stability, with some overall increase, has been a characteristic of this ratio since 1982.

A relatively optimistic picture of recent U.S. manufacturing developments can be derived from the output and factor input dynamics analyzed above. The negative manufacturing multifactor productivity growth recorded during 1973–79 was due to stagnating output combined with a spurt in capital service inputs, while labor hours also increased. Both output and multifactor productivity growth have since recovered.

Germany. Although the manufacturing *multifactor productivity* increase of 2.6 percent per year over the 1956-90 period (2.3 percent, 1956-93) represented substantial growth, it slowed significantly after 1973 (1.8 percent per year, 1973–90), and especially after 1979 (1.3 percent per year, 1979–90). German manufacturing multifactor productivity growth slowed even though combined labor and capital inputs were, on average, decreasing after 1973. In 1990-93, multifactor productivity declined 0.4 percent annually due to an output decline of 2.2 percent per year that was not matched by an equal decline in inputs. For 1992 and 1993, multifactor productivity declined 2.5 percent and 1.2 percent.

German manufacturing *output* grew at an average rate of 3.6 percent annually during the 34-year period 1956–90, slightly faster than U.S. manufacturing output. However, the rate of growth has been dropping steadily. Similar to the United States, very rapid growth occurred before 1973 (5.9 percent annually) and a slowdown took place after that (1.4 percent per year, 1973–90). But unlike the United States, there was no recovery in the output growth rate during the latter years of the 1973–90 period. On the contrary, the 1979-90 period registered slower growth (1.2 percent per year) than the 1973–79 period (1.8 percent per year). Thus, although the 1973–79 period may be treated as an aberration in the United States, with growth recovering after 1979, this is not true for Germany, at least not yet.

Labor hours worked in German manufacturing show a declining trend throughout the entire 1956–90 period, particularly in the 1973–79 period (and since 1990). All the labor input period averages are negative. (See table 1.) It was only in the 1984–90 period that some stability seems to have been restored. The result has been respectable gains in labor productivity even during the 1970's, despite the slowdown in production. The reductions in labor inputs were especially sharp in 1990–93, with a decline of 9.1 percent recorded in 1993. In 1990, hours worked were 22 percent below their 1973 level, and almost 30 percent below their 1956 level (29 and 36 percent below as of 1993).

As in the United States, the input of *capital services* in German manufacturing is characterized by steady growth over the entire period under study. This is due in large part to the way that capital inputs are measured: as a weighted summation of past investments in capital assets. However, great disparities separate the average growth rates of capital inputs for the different time periods. While there was strong average growth over the period as a whole, the increases were much greater before 1973 than after 1973, and especially in the 1979–90 period. The average annual increases declined from 7.4 percent during 1956–73 to 2.5 percent during 1973–79, to a relatively anemic 1.8 percent per year in the 1979–90 period; the slowest growth occurred in the interval 1982–88. Capital service inputs increased at an average annual rate of 2.4 percent in the 1990–93 period.

The combination of increasing capital service inputs and generally declining labor inputs resulted in only small net annual increases of 1 percent in combined *labor and capital inputs* for the whole 1956–90 period. In the earlier, pre-1973 years, capital input increases dominated, resulting in a net average increase of 2.4 percent for labor and capital. The decline in this series in all periods since then is due to reductions in labor hours, because capital inputs continued to increase, although at decreasing average rates. During the 1979–90 period, the declines in labor inputs were roughly offset by the capital input increases, resulting in only a slight net decline in labor and capital inputs of 0.1 percent per year. Combined factor inputs declined sharply—6.5 percent in 1993—because of the sharp drop in hours and only a small increase in capital services.

Changes in the ratio of *capital service inputs to labor hours* are an indicator of capital for labor substitution; these increased in each of the 37 years betwen 1956 and 1993. Capital-for-labor substitution proceeded very rapidly during 1956–73, at an average rate of 8.1 percent annually, slowing to a still significant average of 5.1 percent annual rate during 1973–79, and slowing further to 2.7 percent annually in 1979–90.

Examining the changes in *capital productivity*, the average *output to capital input* ratio declined during all the time periods. As a result, net capital investment in manufacturing increased, on average, faster than manufacturing output during every period.

Based on the developments in manufacturing output and factor inputs described above, one can see that the declining trend in German manufacturing multifactor productivity growth in recent years can be traced to a steady reduction in the output growth rate, in combination with relative stability of factor inputs. Thus, manufacturing multifactor productivity seems to be following and mirroring movements in manufacturing production.

France. Manufacturing *multifactor productivity* grew at an impressive average 3.4 percent annually over the entire 1956–90 period (3.1 percent, 1956–93), above the corresponding results for either the United States or Germany. (See table 1.) This breaks down to an average annual increase of 4.4 percent during 1956–73, and a still respectable annual 2.4 percent during 1973–90.

But the average rate of increase declined over the latter period, so that increases in manufacturing multifactor productivity have been much smaller in more recent years, growing at only 2.1 percent annually during 1979-90. The 1973–90 slowdown in manufacturing multifactor productivity growth occurred despite declines in combined labor and capital inputs, because the growth rates of manufacturing output declined more rapidly. Results for the early 1990's are worse, with multifactor productivity declines of 1.4 percent in 1991 and 0.5 percent in 1993 due to declines in manufacturing output that were not matched by equal declines in labor and capital factor inputs.

French manufacturing *output* increased constantly until 1975, when the first downturn occurred, but growth rates declined over time. Despite a brief growth spurt in the late 1980's, French manufacturing output stagnated during the 1980's and the beginning of the 1990's. As in Germany, the results since 1979 were worse than for 1973–79. Manufacturing output rose at an average annual rate of only 1.0 percent during 1979–90, and declined each year during 1991–93.

Labor input in French manufacturing grew at a moderate upward trend of 0.5 percent annually during 1956–73, after which a steady and steep decline set in. Total labor hours fell 2.1 percent annually during the 1973–90 period and 3.0 percent annually in 1990–93. Total hours worked in 1990 were 30 percent less than in 1973, and 23 percent below the number of hours worked in 1956. As of 1993, total hours worked were down 36 from 1973 and 30 percent lower than in 1956.

As with the other countries covered by the present study, the French manufacturing industry has been increasing its productive capital asset base throughout the period covered, so that *capital service* inputs have grown every year in real terms, even during recessions. However, as in Germany, the rate of growth has been declining over the years. Therefore, growth rates vary greatly for the different time periods, ranging from a high average of 6.6 percent per year in 1956–73 to a low of 2.0 percent per year in 1979–90 (and even lower in 1990–93). The slowest growth in capital service inputs occurred during 1982–86 (and in 1992–93).

The combination of increases in capital service inputs and the generally declining labor inputs results in an average annual growth rate of 0.7 percent in *labor and capital inputs* over the 34-year period of 1956–90. In the earlier, pre-1973 years, the increases in capital service inputs dominated this aggregate, so that combined labor and capital inputs grew at an average annual rate of 2.3 percent. In the later, post-1973 years of 1973–90, capital service inputs grew at a slower rate and labor input declined. As a result, labor and capital inputs also declined, at an annual rate of 0.9 percent.

The ratio of *capital services input to hours worked,* a measure of the rate at which capital is being substituted for labor, rose in each of the 37 years in the 1956–93 interval, indicating that capital inputs were growing faster than labor inputs during this entire period. The rate of capital-for-labor substitution was relatively stable among the various time periods, although it proceeded at a somewhat faster pace before 1973. The ratio grew between a high average annual rate of 6.1 percent during 1956–73 and a low 4.3 percent annual rate in the more recent 1979–90 period.

Capital productivity rose slightly during 1956–73, but has since declined because capital service inputs grew faster than manufacturing output.

French manufacturing recorded respectable gains in multifactor productivity throughout the 1956–90 period as a whole. Before 1973, manufacturing output rose nearly 7 percent annually and multifactor productivity increased 4.4 percent annually. After 1973, a worsening multifactor productivity trend can be observed as a steadily declining growth rate of real manufacturing output is confronted with a relatively stable combination of factor inputs. However, the 2.1 percent annual multifactor productivity growth rate during 1979–90 is still respectable, essentially matching the U.S. figure for the same period of 2.0 percent per year. Nevertheless, these data show that a decline in French manufacturing multifactor productivity occurred after 1973.

Sources of labor productivity growth

For notational convenience, equation 1 can be rewritten as[10]

$$(7)\, d\ln(MFP_t) = d\ln(GPO_t) - \overline{w}_{l,t} \times d\ln(L_t) - \overline{w}_{k,t} \times d\ln(K_t)$$

The term $d\ln(X_t)$ also serves as an expression for $(X_t/X_{t-1} - 1)$, to indicate the percent change in X at time t. Noting that $\overline{w}_{l,t} + \overline{w}_{k,t} = 1$, and re-arranging terms in equation (7), we get

$$(8) \qquad d\ln\left(\frac{GPO_t}{L_t}\right) = d\ln(MFP_t) + d\ln\left(\frac{K_t}{L_t}\right) \times \overline{w}_{k,t}$$

This indicates that changes in labor productivity (output per hour) can be analyzed as the sum of changes in *multifactor productivity* and changes in the ratio of *capital service inputs to labor hours,* the latter multiplied by capital's share of the output value. The term representing the product of the *capital services per hour* ratio and the capital income share ($d\ln[K_t / L_t] \times \overline{w}_{k,t}$) can be interpreted as a capital-for-labor substitution effect. In this way growth in labor productivity can be separated into a multifactor productivity effect and a capital/labor substitution effect.

Labor productivity changes are examined in the three countries, to determine the role of these two effects in those changes. (See table 2.)

Labor productivity in U.S. manufacturing grew an annual average 3.1 percent over the 1956–93 period, somewhat faster before 1973 (3.8 percent per year) than afterward (2.3 percent per year). Labor productivity barely grew in 1973–79, when output rose little more than 1 percent per year. (See table 2.) Of all the periods, the highest labor productivity growth was registered in 1990–93 (4 percent per year).

Vigorous capital-for-labor substitution contributed to this growth in labor productivity, but it is only part of the explanation. In most periods, MFP was more important in explaining labor productivity gains. (See table 2.) Before 1973, most

Table 2. Sources of manufacturing labor productivity growth, U.S., Germany, and France, selected periods, 1956–93 (in percent)

	Output per hour	Capital-labor substitution effect	Multifactor Productivity
United States			
1956–90	3.0	1.0	2.1
1956–93	3.1	1.0	2.1
1956–73	3.8	0.8	2.9
1973–90	2.3	1.1	1.2
1973–79	.8	1.1	–.2
1979–90	3.1	1.1	2.0
1990–93	4.0	1.1	2.8
Germany			
1956–90	4.7	2.0	2.6
1956–93	4.4	2.0	2.3
1956–73	6.5	3.1	3.4
1973–90	2.9	1.1	1.8
1973–79	4.3	1.7	2.6
1979–90	2.1	.8	1.3
1990–93	1.2	1.7	–.4
France			
1956–90	5.0	1.5	3.4
1956–93	4.6	1.5	3.1
1956–73	6.3	1.8	4.5
1973–90	3.7	1.3	2.4
1973–79	4.5	1.5	3.0
1979–90	3.2	1.2	2.1
1990–93	1.2	1.7	–.4

of the increases in labor productivity were accounted for by strong growth in multifactor productivity. Although capital service inputs were growing faster than labor inputs throughout this period, the substitution of capital for labor was relatively moderate, particularly when compared with Germany and France.

This changed somewhat after 1973, as growth in multifactor productivity tended to weaken, while the substitution of capital for labor became more intense. In the 1973–79 period, U.S. manufacturing multifactor productivity declined slightly, but labor productivity still managed to grow an annual average 0.8 percent because of very strong increases in capital service inputs, and the resulting shift in the capital/labor input ratio. But while the increasing capital/labor input ratio continued to be an important contributor to the growth of labor productivity in U.S. manufacturing in the 1979–90 period, multifactor productivity growth also recovered, and was again a more important factor in explaining labor productivity growth. Multifactor productivity growth also was the more important factor in the 1990–93 period.

Thus, of the two factors, capital-for-labor substitution and multifactor productivity, the latter turned out to be more important in explaining changes in U.S. labor productivity. The exception was 1973–79, when MFP showed a small decline.

In the German manufacturing sector, labor productivity recorded impressive gains over the period as a whole, but with declining annual increases. Over the 1956–90 time period, and for most of the sub-periods examined in this study, growth in multifactor productivity also was the more important factor in explaining these increases. Capital-for-labor substitution was particularly vigorous before 1973, but MFP was still more important in explaining the improvement in labor productivity. However, given the strong capital-for-labor substitution in German manufacturing over most of this same period, this factor was, not surprisingly, almost as important. Also, in the most recent 3 years, 1990–93, when MFP declined, the capital/labor substitution effect was greater than the MFP effect.

Average increases in all periods, but on a declining trend, also characterize labor productivity in the French manufacturing sector over the 1956–90 period. French manufacturing multifactor productivity growth, despite somewhat slower growth in the more recent time periods, also recorded steady increases in all the time periods examined, except for 1990–93. And despite the strong capital-for-labor substitution in France, manufacturing multifactor productivity still played the major explanatory role in determining the manufacturing sector's growth in labor productivity during most periods. As in German manufacturing, the exception was in 1990–93, when manufacturing multifactor productivity declined. But the capital-for-labor substitution effect, while playing a secondary role, did contribute significantly to the improvement of labor productivity.

Within all three countries, manufacturing multifactor productivity is therefore a more important explanatory factor than capital-for-labor substitution in explaining labor productivity growth (but not in explaining differences in labor productivity growth between the countries, as will be seen in the following section).

In sum, growth in each country's *capital/labor input* ratio is insufficient by itself to explain the strong growth in labor productivity observed in the different countries and time periods. Other factors—those that are encompassed by the concept of multifactor productivity—must also be considered.

Comparisons among countries

United States and Germany. Over the 1956–90 period, German manufacturing multifactor productivity grew slightly faster, at 2.6 percent per year, than its United States counterpart, which grew at an annual 2.1 percent average. However, the German multifactor productivity annual growth rate has been declining: 1956–73, 3.4 percent; 1973–79, 2.6 percent; and 1979–90, 1.3 percent. (Multifactor productivity was negative in the 1990's.) On the other hand, U.S. manufacturing multifactor productivity has recovered from the 1973–79 decline, and increased faster than the German equivalent in the 1979–90 period (and in 1990–93).

Output growth can be broken down into the two components of growth in combined labor and capital inputs and in multifactor productivity, although the relationship is only approximate with annual data. (See table 3.) Before 1973, manufacturing output grew strongly in both countries, although the German growth rate was somewhat greater (4.6 percent per year in the United States and 5.9 percent per year in Germany). During these same years, capital service inputs increased about twice as fast in Germany.

However, while hours worked were declining in German manufacturing at the rate of 0.6 percent per year, U.S. hours increased at the rate of 0.8 percent per year. The net result was that, although the use of combined factor inputs increased more in Germany than in the United States (an annual rise of 2.4 percent versus 1.6 percent), German multifactor productivity grew marginally faster over this 17-year period; the average difference was 0.4 percentage points per year.

After 1973, the dynamics in the two manufacturing sectors changed somewhat. U.S. manufacturers increased their capital service inputs at a more rapid pace than in Germany, and, while U.S. labor hours increased less than previously, or even declined, labor input in German manufacturing shrank much more. The net result was that total factor in-

Table 3. Contribution of labor and capital and multifactor-productivity to manufacturing output growth, United States versus Germany and France, selected periods, 1956–93

[Average annual percent changes and country differences in rates of change]

Period and country	Manufacturing output growth	Labor and capital input growth	Multifactor productivity growth
Germany–U.S.			
1956–90:			
Germany	3.6	1.0	2.6
United States	3.3	1.2	2.1
Difference	.3	–.2	.5
1956–93:			
Germany	3.1	.8	2.3
United States	3.2	1.1	2.1
Difference	–.1	–.3	.2
1956–73:			
Germany	5.9	2.4	3.4
United States	4.6	1.6	2.9
Difference	1.3	.8	.4
1973–90:			
Germany	1.4	–.4	1.8
United States	2.0	.8	1.2
Difference	–.6	–1.1	.5
1973–79:			
Germany	1.7	–.8	2.6
United States	1.2	1.4	–.2
Difference	.6	–2.2	2.8
1979–90:			
Germany	1.2	–0.1	1.3
United States	2.5	.4	2.0
Difference	–1.3	–.5	–.7
1990–93			
Germany	–2.2	–1.8	–.4
United States	2.6	–.2	2.8
Difference	–4.8	–1.6	–3.2
France—U.S.			
1956–90:			
France	4.1	.7	3.4
United States	3.3	1.2	2.1
Difference	.8	–.5	1.3
1956–93:			
France	3.6	.5	3.1
United States	3.2	1.1	2.1
Difference	.4	–.6	1.0
1956–73:			
France	6.8	2.3	4.4
United States	4.6	1.6	2.9
Difference	2.2	.6	1.5
1973–90:			
France	1.5	–.8	2.4
United States	2.0	.8	1.2
Difference	–.5	–1.6	1.2
1973–79:			
France	2.6	–.4	3.0
United States	1.2	1.4	–.2
Difference	1.4	–1.8	3.2
1979–90:			
France	1.0	–1.1	2.1
United States	2.5	.4	2.0
Difference	–1.5	–1.5	.0
1990–93:			
France	–1.8	–1.4	–.4
United States	2.6	–.2	2.8
Difference	–4.5	–1.2	–3.3

puts in German manufacturing fell, although they still grew in the United States. In the 1973–79 period, growth in U.S. manufacturing output slowed to a rate of 1.2 percent per year, while combined factor inputs grew by 1.4 percent per year, resulting in a small decline in multifactor productivity. During this same period, the German manufacturing sector posted annual increases of 1.7 percent in output and 2.6 percent in multifactor productivity. But in the later period, 1979–90, German manufacturing output growth averaged only 1.2 percent annually and multifactor productivity 1.3 percent annually, while U.S. output increased by 2.5 percent per year and U.S. multifactor productivity increased by 2.0 percent per year.

These results suggest that comparative growth rates of manufacturing multifactor productivity should not be viewed as fundamental, secular trends, where one country dominates another over extended periods of time. Rather, multifactor productivity growth depends on relationships among outputs and inputs that vary cyclically, and can change in a relatively few years.

We can examine how changes in *labor productivity* (output per hour) differ in the manufacturing sectors of the United States and Germany. One can again begin with relationship

$$d\ln\left(\frac{GPO_t}{L_t}\right) = d\ln(MFP_t) + d\ln\left(\frac{K_t}{L_t}\right) \times \overline{w}_{k,t} \quad (8)$$

Because we want to examine differences in growth rates between the United States and Germany, let us call D(~) the difference between the respective growth rates of the measures shown in the parentheses. Relationship 8 can then be broken down into:[11]

$$D\left(\frac{GPO_t}{L_t}\right) \equiv D\left(\frac{K_t}{L_t}\right) \times \left[avg.\overline{w}_{k,t}\right] + D\left(\overline{w}_{k,t}\right) \times \left[avg.\,d\ln\left(\frac{K_t}{L_t}\right)\right] + D(MFP_t) \quad (9)$$

where $\left[avg.\overline{w}_{k,t}\right]$ and $\left[avg.\,d\ln\left(\frac{K_t}{L_t}\right)\right]$ are the arithmetic averages of these variables for the two countries being compared.

In this way the difference in labor productivity growth between the two countries is expressed as a sum of three additive factors: difference in changes in capital inputs per hour, multiplied by the (two-country) average capital share in the value of output; difference in capital shares, multiplied by the (two-country) average change in capital inputs per hour; and difference in multifactor productivity growth. These three factors may be designated by the summary terms of: the *capital-for-labor substitution difference*, the *capital share difference*, and the *multifactor productivity difference.* It should be remembered that the above relationship holds only approximately for annual data.

This analysis was carried out for the various time periods, and the results are summarized in table 4. For the 34-year

Table 4. Sources of differences in manufacturing labor productivity growth, United States versus Germany and United States versus France, selected periods, 1956–93

Period	Output per hour	Capital-labor substitution difference	Capital share difference	Multifactor productivity difference
Germany minus U.S. averge growth rate:				
1956–90	1.6	0.7	0.4	0.5
1956–93	1.3	.6	.3	.2
1956–73	2.8	1.7	.7	.4
1973–90	.5	–.2	.2	.5
1973–79	3.5	.3	.3	2.8
1979–90	–1.1	–.5	.1	–.7
1990–93	–2.8	.6	.0	–3.2
France minus U.S. average growth rate:				
1956–90	1.9	.5	.1	1.3
1956–93	1.5	.5	.1	1.0
1956–73	2.5	.9	.1	1.5
1973–90	1.3	.1	.0	1.2
1973–79	3.6	.3	.0	3.2
1979–90	.1	.0	.0	.0
1990–93	–2.8	.3	.2	–3.2

period of 1956–90, labor productivity grew faster in German manufacturing, by an average 1.6 percentage points per year. All three factors apparently played a role in this result. To get a better understanding of the underlying forces at work, it is better to examine the different periods separately.

In the 17 years before 1973, labor productivity in the German manufacturing sector increased by an annual average 6.5 percent against 3.8 percent per year in the United States. Most of the difference (2.8 percentage points) can be traced to the *capital-for-labor substitution difference*. The *capital share difference*, though much less important, was the next biggest contributor to the above outcome. It should be mentioned at this point that for most of the time period studied, the capital share in German manufacturing was larger than the corresponding variable in the United States, helping to maintain faster growth in German manufacturing labor productivity. The capital share in the United States fluctuated between 0.23 and 0.30, while in Germany it began above 0.40 in 1956 and subsequently declined. In 1980 it reached the U.S. range, and even fell below the U.S. value in the last 2 years, at 0.24 vs. 0.28 for the United States in 1993. Thus, this factor played a somewhat more important role in the earlier years of the period under study and has become less important in more recent years.

During the period 1973–90, the increases in labor productivity were very similar in the manufacturing sectors of both countries, with Germany holding an advantage of an average 0.5 percentage point per year. But the rate at which capital was substituted for labor in U.S. manufacturing approached or surpassed the corresponding German rate (these rates became more alike), so that the difference in multifactor productivity became relatively more important. However, this period must be broken down into the first stage, 1973–79, during which German labor productivity grew much faster, 4.3 percent vs. 0.8 percent per year, and the second stage, 1979–90, when U.S. labor productivity pulled ahead, 3.1 percent vs. 2.1 percent per year.

During 1973–79, almost all of the faster increase in German manufacturing labor productivity was accounted for by more rapid increases in German manufacturing multifactor productivity, which rose by an annual average 2.6 percent while U.S. manufacturing multifactor productivity declined by 0.2 percent per year. The two sectors' capital/labor input ratios grew by about the same amount, separated by less than 1 percentage point per year.

In the period 1979–90, U.S. labor productivity increased faster, and the difference in manufacturing multifactor productivity growth rates was again the primary reason, although faster capital-for-labor substitution in the United States also played a significant role. The capital share difference still favored German labor productivity, but its influence had become minimal (the two capital shares had become very similar).

One may conclude that over the 1956–90 period, the *capital-for-labor substitution* difference was the major factor in explaining the differences in labor productivity growth rates in the U.S. and German manufacturing sectors.

The *multifactor productivity* difference was next in importance. Note that the factors that explain labor productivity growth *within* a country's manufacturing sector are not necessarily the same factors that explain differences in labor productivity growth *between* countries. In the previous section about sources of labor productivity growth, multifactor productivity was found to be more important than capital-for-labor substitution in explaining each country's increase in labor productivity. Now, in comparing U.S. and German labor productivities, the reverse is true. This overall outcome was determined by the pre-1973 developments, where capital/hours growth rates in the two countries differed much more, while multifactor productivity growth rates were more similar. But multifactor productivity played a much more important role in later years, when capital-for-labor substitution slowed in Germany and accelerated in the United States, bringing the two rates closer.

Before 1973, the *capital share* difference (the higher German level) was a relatively important factor in keeping German labor productivity growing faster. Over the years, as the German capital share became more similar to the U.S. capital share, this difference became less important.

United States and France. Over the 1956–90 period, manufacturing multifactor productivity in France grew at a faster pace than multifactor productivity in U.S. manufacturing, at an annual average rate of 3.4 percent vs. 2.1 percent. (See table 3). However, the French multifactor productivity annual growth rate slowed over the period: 1956–73, 4.4 percent; 1973–79, 3.0 percent; and 1979–90, 2.1 percent. The vigorous turn-around in multifactor productivity growth shown by U.S. manufacturing in the 1980's and 1990's was not matched by French manufacturing.

The reason for the better overall French performance was that, while manufacturing output in France grew somewhat faster during the 1956-90 period, U.S. combined factor (labor and capital) inputs increased at nearly twice the rate of the French (1.2 percent vs. 0.7 percent per year). This greater improvement in the use of factor inputs by French manufacturing was accomplished in part by saving labor. Although capital service inputs rose strongly in both manufacturing sectors (France somewhat more, 4.6 percent per year vs. 3.9 percent per year in the United States), French labor hours declined by about 1 percent annually, while manufacturing labor hours kept growing in the United States until the 1980's.

After 1973, U.S. capital service inputs grew faster than those in French manufacturing, especially after 1979. With labor hours in French manufacturing continuing to decline faster than in the United States, this further widened the gap between U.S. and French labor and capital inputs. French factor inputs declined throughout the 1973–90 period, even as manufacturing output grew at an average 1.5 percent per year. During this same period, combined U.S. factor inputs kept increasing. This contributed to better French multifactor productivity performance. U.S. multifactor productivity grew faster than French manufacturing multifactor productivity only in the most recent 1990–93 period, when French output fell and French manufacturing multifactor productivity turned negative.

To examine differences in *labor productivity* growth rates in the manufacturing sectors of the United States and France, we will use the same analytic tool that was used in the German comparisons breaking down differences in labor productivity growth into three additive factors: the *capital-for-labor substitution difference*, the *capital share difference*, and the *multifactor productivity difference* (equation 9).

For the entire 1956–90 period, French labor productivity increased at a faster annual rate, 5 percent vs. 3 percent in the United States, for a difference of 2 percentage points (see table 4). French labor productivity grew faster in all periods (except 1990–93), although the difference was negligible in the 1979–90 period. Most of this difference in growth rates was accounted for by more rapid multifactor productivity increases in the French manufacturing sector (3.4 percent vs. 2.1 percent per year). The substitution of capital for labor (i.e. changes in the ratio capital/labor inputs) proceeded at a faster pace in French manufacturing in most of the periods studied, but the margin above the corresponding U.S. rate diminished over time.

This difference in substitution rates (growth in capital services per hour) equaled 3.1 percentage points per year in 1956–73, 1.3 percentage points per year in 1973–79, and essentially no difference in 1979-90. While the capital-for-labor substitution difference had a relatively greater weight before 1973 than after 1973, multifactor productivity was always the most important factor in explaining differences in U.S.-French labor productivity growth. This is unlike the German-U.S. comparison, in which the capital-for-labor substitution difference before 1973 was more important. In 1979-90, all three factors were approximately nil; labor productivity grew at approximately the same average rate in both countries.

Although multifactor productivity was the most important factor, the rapid substitution of capital for labor in French manufacturing also contributed significantly to the labor productivity growth differential. The *capital share* difference played a negligible role in explaining differences in labor productivity.

While multifactor productivity is important in explaining labor productivity differences, there is no clear indication that one country's long-term trend in manufacturing sector multifactor productivity is inherently stronger. As in the U.S.-German comparisons, cyclical considerations play a part in determining comparative advantage, as the post-1990 switch in U.S.-French leadership in multifactor productivity demonstrates.[12]

General observations

In all three countries, *multifactor productivity* increased in most years, with the fastest growth rates recorded before 1973. But multifactor productivity declines occurred in all three countries during periods in which output was cut severely, as in 1973–79 in the United States and 1990–93 in Germany and France. Although Germany and France had better multifactor productivity growth results for the period as a whole, their rates of multifactor productivity growth declined steadily over the years, showing negative rates in 1990–93. By contrast, multifactor productivity growth resumed in the United States after 1979, and although U.S. manufacturing multifactor productivity increased most rapidly in 1956–73 (2.9 percent per year), it grew nearly as fast after 1979. Such a resumption in multifactor productivity growth has not yet been observed in Germany and France. However, unlike the United States, Germany and France have not yet recovered from the economic downturns that affected the three countries at the beginning of the 1990's.

Manufacturing *output* slowed in the three countries after 1973, particularly in the United States. But while U.S. output recovered significantly after 1979, such a recovery is not yet evident in German or French manufacturing.

In Germany and France, *labor hours* declined over the 1956–93 period. In France, labor hours increased a modest 0.5 percent per year before 1973, but experienced strong declines since then. In Germany, labor hours fell in all the periods. The average yearly declines in labor hours in both countries frequently reached 2 percent to 3 percent. In the United States, labor hours increased slightly in manufacturing for the period as a whole, but U.S. labor input declined after 1979. However, the U.S. rate of decrease since 1979 has been much slower than in Germany or France.

In all three countries, *capital inputs* increased strongly during the period as a whole, with growth occurring in all sub-periods. In Germany and France, however, these increases were much greater before 1973; their rates of increase have declined steadily since then. In the United States, capital inputs grew quite vigorously and fairly steadily during the period, with relatively little variation in growth rates among the different time periods. In contrast to what occurred in Germany and France, capital inputs grew faster after 1973 than before.

Combined labor and capital inputs increased in the three countries before 1973. After 1973, combined factor inputs declined in Germany and France, as cuts in labor hours more than offset increased capital service inputs. In the United States, average annual increases of combined factor inputs occurred in each time period, except for a slight decline in 1990–93, although the rate of increase slowed somewhat.

The ratio of *capital service inputs to labor hours* increased in the three countries, indicating that capital was being substituted for labor. In Germany and France, this process was especially noticeable before 1973. In the United States, on the other hand, the more vigorous capital-for-labor substitution occurred after 1973.

Labor productivity increased in the United States in all periods, although just barely in 1973–79, when output stagnated. The pre-1973 rate of increase was slightly faster than the post-1973 rate. In Germany and France, labor productivity also increased in all periods, but the pre-1973 rates were much stronger. □

Footnotes

[1] For a summary of the state of the art, see Dale W. Jorgenson, "Productivity and Economic Growth," in E.R. Berndt and J.E. Triplett, eds., *Fifty Years of Economic Measurement: The Jubilee of the Conference on Research in Income and Wealth* (University of Chicago, 1990), pp. 19–118.

[2] The principal reference to the method used in this study to measure multifactor productivity is *Trends in Multifactor Productivity, 1948–81*, Bulletin 2178 (Bureau of Labor Statistics, 1983).

[3] Before 1960, the source data series did not include West Berlin or the Saar region. Results with and without these two areas were published for 1960; they were used to link the data series.

[4] The Bureau of Economic Analysis has annouced that, later this year, it will feature the index of real GDP based on its "chain type" annual weights measure instead of the "fixed weight" measure. However, BEA does not publish a chain-type annual-weighted measure for manufacturing.

[5] For a description of alternate ways to compute real output, and for a discussion of changes in the U.S. statistical program, see Allan Young, "Alternative Measures of Changes in Real Output and Prices," *Survey of Current Business*, April 1992, pp. 32–52.

[6] For comparison, an index of French manufacturing real value added also was computed using annual chain-weighted estimates. The results showed only a slight difference in the growth rates of the two series, with the benchmark-years-weighted series growing somewhat faster.

[7] The French employee compensation figures for 1956–58 and 1991–93 are BLS estimates.

[8] For a more complete discussion about the perpetual inventory method of estimating capital stock, and of imputed rent calculations, see *Trends in Multifactor Productivity, 1948–81*, September 1983.

[9] This also is true for capital input growth in the manufacturing industries of Germany and France. This result is at least partly due to the method used to estimate capital stock (the perpetual inventory method).

[10] In general, for any number X, if the change in X (or ΔX) is sufficiently small, then

$$\ln(1+\Delta X/X) \approx \Delta X/X = \left(\frac{X+\Delta X}{X} - 1\right) \text{ and } \lim_{\Delta X \to 0} \ln\left(1 + \frac{\Delta X}{X}\right) = d\ln(X)$$

[11] Breaking down the difference between the two products $d\ln\left(\frac{K_t}{L_t}\right) \times \overline{w}_{k,t}$ is according to the following scheme, using $a_x b_x - a_y b_y$ as illustrative variables:

$$\begin{aligned} a_x b_x - a_y b_y &= \tfrac{1}{2}a_x b_x + \tfrac{1}{2}a_x b_x - \tfrac{1}{2}a_y b_y - \tfrac{1}{2}a_y b_y + \tfrac{1}{2}\left(a_x b_y - a_x b_y + a_y b_x - a_y b_x\right) \\ &= \tfrac{1}{2}a_x\left(b_x + b_y\right) - \tfrac{1}{2}a_y\left(b_x + b_y\right) + \tfrac{1}{2}b_x\left(a_x + a_y\right) - \tfrac{1}{2}b_y\left(a_x + a_y\right) \\ &= \left(a_x - a_y\right)\tfrac{1}{2}\left(b_x + b_y\right) + \left(b_x - b_y\right)\tfrac{1}{2}\left(a_x + a_y\right) \end{aligned}$$

[12] To examine the reasons for the European manufacturing slowdown relative to the United States, and what trend or cyclical forces are at work, factors such as exchange rate movements and unit labor cost comparisons also must be considered. Two recent studies of these issues are available in Bart van Ark, "Manufacturing prices, productivity, and labor costs in five economies", *Monthly Labor Review*, July 1995, pp. 56–72; and Mary Greiner, Christopher Kask, and Christopher Sparks, "Comparative manufacturing productivity and unit labor costs,"*Monthly Labor Review*, February 1995, pp. 26–38.

Appendix

Factor input prices

Let us define an aggregate price for manufacturing output, Po, by dividing output at current prices by real output; an hourly price of labor, Pl, by dividing total labor compensation by total hours worked; and a price of capital services, Pk, by dividing total income to capital by capital service inputs. With these newly defined variables, equation 1 can be restated as

$$\text{(A-1)} \quad \ln\left(\frac{MFP_t}{MFP_{t-1}}\right) = \tfrac{1}{2}(w_{l,t-1} + w_{l,t}) \times \ln\left(\frac{Pl_t}{Pl_{t-1}}\right) + \tfrac{1}{2}(w_{k,t-1} + w_{k,t}) \times \ln\left(\frac{Pk_t}{Pk_{t-1}}\right) - \ln\left(\frac{Po_t}{Po_{t-1}}\right)$$

Equation A-1 is referred to as the *dual* formulation of equation 1, (see p. 40) which is then called the *primal* formulation.[1] Whereas in equation 1 multifactor productivity increases when output grows more than the combined factor inputs, in equation A-1 multifactor productivity increases when the output price grows less than the combined factor prices. It should be noted that the variables MFP, w_l, and w_k are the same in both formulations. Table A-1 presents the growth rates of these three price series, for the three countries and the periods being compared. In all cases, the hourly price of labor is seen to be growing more rapidly than the price of capital service inputs. The capital service price increases appear particularly low in German manufacturing.

The perpetual inventory method

To avoid additional subscripts, the following description is in terms of a single asset category. A similar approach, but with different parameters, would be applied to each category in turn. The perpetual inventory method is applied to depreciable assets only.

Although we are dealing with only one asset category, this category consists of a large number of individual units, and these units have differing useful lives (*L*). The actual lives for this asset category are assumed to be distributed in the form of a symmetric pattern, which can be approximated by a truncated normal probability distribution, *P(L)*, which is assumed to be ±2 standard deviations around the mean asset life.

The contribution that any unit of capital makes to the production process declines with the asset's age. Here we assume a hyperbolic age-efficiency function

$$\text{(A-2)} \qquad e(i) = \frac{L-i}{L-\beta\, i} \qquad \text{for } 0 \le i < L$$

where i is age, L is useful life, and $e(i)$ is the unit's relative efficiency at age i. Relative efficiency is equal to 1.0 when the asset is new, and then declines to 0 when its useful life ends at age $i=L$. The curvature parameter β determines the pattern of efficiency loss, and lies between 0 and 1. This is a parameter of the particular asset category. For the three countries, β is assumed to be 0.50 for equipment and 0.75 for structures. The form of the hyperbolic age-efficiency function implies that efficiency declines more rapidly as assets age.

Next we define the relative efficiency of the entire asset category at age *i*, or *a(i)*, as the weighted average of the individual unit efficiencies, each one weighted by its relative frequency *P(L)*

$$\text{(A-3)} \qquad a(i) = \sum_{L=i}^{Lmax} P(L)\frac{L-i}{L-\beta\, i} \qquad \text{for } i \le L$$

Lmax is the maximum useful life of an asset belonging to this particular category. The quantity of real productive capital stock on hand at the end of year *t*, for this particular asset category, or *K(t)*, is then computed as a summation of all past investments (*I*) that could still be in operation at time *t*, with the investments of every age (or vintage) being discounted by *a(i)*

$$\text{(A-4)} \qquad K(t) = \sum_{i=0}^{Lmax} a(i) \times I(t-i)$$

The *a(i)* are a decreasing function of *i*, so that the older the assets the less their contribution to *K(t)*.

Capital stock estimates and service lives

Formulas A-2, A-3, and A-4 indicate that the computed capital stock level K(t) for a given depreciable asset category is affected by the service lives of the units that comprise this category. For the manufacturing industry in Germany, the estimated average service lives of the two asset categories used are based on a study by Wolfgang Kirner,[2] and are 22 years for equipment and 43 years for structures.

For the manufacturing industry in France, the service lives are based on data published by the French national statistical institute,[3] and the estimated averages are: 10 years for transportation equipment, 18.47 years for equipment other than transportation, and 36.84 years for structures. Transportation and other equipment were combined into a single equipment category for the analysis performed for this article. The United States capital input series is based on 29 categories of equipment and 29 categories of structures. The median service life of the former is 12 years, and the median service life of structures is 38 years.

We will now examine the sensitivity of the estimated trends in capital service inputs to the length of service life assumed for a given asset category. Using equation A-4, subtract K(t)-K(t-1), then on the right-hand-side multiply and divide each term by I(t-1-i), and finally divide each side by K(t-1). The result is

$$\text{(A-5)} \qquad \%\Delta K(t) = \sum_{i=0}^{Lmax} \%\Delta I(t-i) \times \left[\frac{I(t-1-i)}{K(t-1)} \times a(i)\right]$$

The expressions %ΔK(t) and %ΔI(t-i) are year-over-year percent changes in the capital stock and in the level of investment, in years *t* and (*t-i*) respectively. The terms in the square brackets are weights that sum to one over the span of summation. Therefore, the year-to-year changes in the estimated capital stock are trailing moving averages of past investment changes. From A-5 it is evident that the less variation in the %ΔI series, the less important are the parameters included in the weights. In the limiting case, if we were to assume that investments were growing at a constant rate throughout the period, then the capital stock would grow at exactly the same rate, regardless of the average service life or the β that was used. Although such an assumption is unrealistic, formula A-5 shows that %ΔK does not tend to vary systematically with length of service life.[4] A change in the length of service life will only shift the period over which the %ΔI are averaged, and also modify the weights somewhat. However, the result will still be an average of past investment growth.

The form of the equation suggests that estimates of average capital service growth should be fairly robust for moderate changes in the estimated service lives. To examine this assumption, average annual changes in the capital stock of equipment and structures were estimated for Germany and France, using different service lives. The results are shown in table A-2. The base service lives refer to the averages given in the first paragraphs of this section. These were increased and decreased by given fixed percentages (±10 percent, 25 percent, and 50 percent), and the resulting average annual capital stock changes tabulated. The dash refers to cases where the investment series do not go back far enough to permit the calculations indicated.

In general, the more the service life departs from the base assumption, the more does the computed capital growth differ from the base solution, although this is not always true (e.g., compare the 1956–73 results for German structures, base vs. base-50 percent). In most cases the differences are less than 0.5 percentage point, although there are two cases where the difference is over 1 percentage point (both for base-50 percent: French structures 1956–73, and German structures 1973–90). In particular, it should be noted that the average growth rates computed for the different time periods vary more among each other than do the growth rates in each time span, computed using different service life assumptions.

Imputed rental price of capital

An imputed rental price is calculated for each asset category, using the following equation

$$\text{(A-6)} \quad c_t = \frac{(1-u_t z_t - e_t)\left(p_{t-1}r_t + p_{t-1}\frac{B_t}{K_{t-1}} - \overline{\Delta p_t}\right)}{1-u_t} + p_{t-1}x_t$$

where:

- c Capital rental price
- u Corporate income tax rate
- z Present value of tax deductions for depreciation
- e Investment tax credit
- p Asset price
- r Rate of return on investment
- B Real value of depreciation
- K Real capital stock
- $\overline{\Delta p_t}$ Capital gains (smoothed asset price change)[5]
- x Property tax rate (taxes on capital)

Although the rate of return (r) appears as an independent variable on the right-hand side of equation A-6, it is actually determined simultaneously with c as a function of these same independent variables and of the total property income. For Germany and France, it is assumed that, for every year, all assets have the same rate of return. This rate of return is determined for each country and in each year using the total property income for that year and using the value of the other variables in equation A-6 that pertain to that year. For the U.S., the rates of return are permitted to differ by industry; within industries all assets have the same rate of return for a particular year.

Sectoral output or value added

Sectoral multifactor productivity also can be measured by replacing the output term (real gross product–GPO– or value added) in equation 1with a sector's real gross output. To the primary factor inputs of labor and capital are added other inputs purchased from outside the sector (energy, materials, and business services). For consistency, gross output is defined as output sold outside the sector, or "sectoral output."[6] This approach is particularly appropriate when dealing with detailed industries. The finer the industry breakdown, the smaller the value added as a proportion of sectoral output, and the greater the value of inter-sectoral purchases as a proportion of total factor inputs. Conversely, as sectors become more aggregated, the proportion of value added in sectoral output increases and the proportion of intermediate inputs coming from other sectors declines.

At the total economy level, excluding imports and exports, sectoral output is identical to value added (everything is sold to final users), and the only input factors are labor and capital (nothing purchased from other sectors). If we designate by MFP_{so} and MFP_{va} the multifactor productivity indexes calculated for a given sector by the sectoral output and the value added methods respectively, then it can be shown that in general

$$\text{(A-7)} \quad \frac{\%\Delta MFP_{so}}{\%\Delta MFP_{va}} = \frac{\text{value added, at current prices}}{\text{sectoral output, at current prices}}$$

The advantages of using the sectoral output definition of multifactor productivity are evident. It allows an analysis of the effects on multifactor productivity trends of all intermediate factor inputs, not only of the two primary factors of labor and capital.

The main disadvantages of the sectoral output approach—these become especially formidable in the case of international compari-

Table A-1. Growth rates of prices of manufacturing output and factor inputs, U.S., Germany, and France, selected periods, 1956–93

[Average annual percent changes]

	Output price	Labor price	Capital price
United States			
1956–90	2.9	5.9	2.6
1956–93	2.7	5.8	2.3
1956–73	1.1	5.0	1.5
1973–90	4.8	6.9	3.7
1973–79	8.6	9.6	4.8
1979–90	2.9	5.5	3.2
1990–93	.0	4.8	-1.8
Germany			
1956–90	3.1	8.5	1.1
1956–93	3.1	8.3	.3
1956–73	2.9	10.3	.4
1973–90	3.4	6.8	1.8
1973–79	4.0	9.3	1.6
1979–90	3.1	5.5	1.9
1990–93	2.6	6.4	-8.5
France			
1956–90	5.7	10.5	6.3
1956–93	5.4	9.9	5.5
1956–73	3.7	9.6	5.3
1973–90	7.7	11.3	7.3
1973–79	9.8	15.9	6.3
1979–90	6.6	8.9	7.8
1990–93	1.6	3.7	-3.5

sons—lie in the data requirements. All shipments among firms in the same sector must be identified, deflated, and subtracted from the sector's real gross output and from its purchases of inputs of energy, materials, and services. This is difficult and time-consuming.

Problems of international data availability and timeliness were one factor in the decision to use the value-added method in the multifactor productivity comparisons reported in this article. Another is that it is compatible with the regular international comparisons of manufacturing labor productivity reported by BLS, which also uses real value added as the measure of output. In addition, until recently, BLS regularly reported on U.S. manufacturing multifactor productivity developments based on the value added approach.[7] It is believed that, based on equation A-7, the difference in the results from the two methods should not be large given that the measures reported here deal with the aggregated manufacturing sector.

Table A-2. **Growth in capital stock, results of sensitivity test, selected periods**

Average service life	France			Germany		
	1956–90	1956–73	1973–90	1956–90	1956–73	1973–90
Equipment:						
Base	5.37	8.18	2.64	5.22	8.20	2.33
+10 percent	5.42	8.11	2.78	–	–	2.48
+25 percent	5.46	8.00	2.97	–	–	2.69
+50 percent	5.49	7.79	3.23	–	–	–
–10 percent	5.32	8.22	2.49	5.13	8.18	2.16
–25 percent	5.21	8.25	2.26	4.96	8.11	1.89
–50 percent	5.02	8.22	1.92	4.59	7.75	1.52
Structures:						
Base	2.23	2.76	1.70	3.45	5.81	1.14
+10 percent	2.12	2.55	1.70	3.48	5.73	1.28
+25 percent	1.99	2.32	1.66	3.50	5.63	1.43
+50 percent	1.84	2.09	1.59	–	–	–
–10 percent	2.35	3.02	1.68	3.40	5.89	.96
–25 percent	2.53	3.52	1.55	3.24	5.96	.59
–50 percent	2.72	4.58	.90	2.64	5.81	–.44

Footnotes to the appendix

[1] For a recent discussion of primal and dual measures of multifactor productivity, see Edwin R. Dean and Mark K. Sherwood, "Manufacturing costs, productivity, and competitiveness, 1979–93," *Monthly Labor Review*, October 1994, pp. 3–16.

[2] Wolfgang Kirner, *Zeitreihen für das Anlagevermögen der Wirtschaftsbereiche in der Bundersrepublik Deutschland.* Beitrage zur Strukturforschung, Heft 5. Berlin, Deutsches Institut für Wirtschaftsforschung, 1968.

[3] Institut National de la Statistique et des Etudes Economiques, *Comptes de patrimoine en base 1980*, August 1991, Table 2.1.

[4] This conclusion does not hold for the computed capital stock level, which varies directly with the assumed average service life.

[5] Because the imputed rents are a factor in estimating the Törnqvist weights used for combining the different categories of capital services ($s_{i,t}$ in equation 5), they should normally be non-negative. Negative imputed prices of capital services may arise in years when the price of a capital asset increases rapidly. The explanation for this is that, with sufficiently high capital gains, a capital asset can be owned (and operated) even if the value of its productive services is negative. This is most likely to happen with nondepreciable assets (land and inventories). While productive capital services with a negative price may occur, one would not wish to come up with such an estimate merely as a result of excessive noise in the underlying price series. Smoothing the price changes reduces the risk of this happening. For a discussion of this issue see Michael J. Harper, Ernst R. Berndt, and David O. Wood, "Rates of Return and Capital Aggregation Using Alternative Rental Prices," in Dale W. Jorgenson and Ralph Landau, eds., *Technology and Capital Formation*, MIT Press, 1987.

[6] William Gullickson, "Measurement of productivity growth in U.S. manufacturing," *Monthly Labor Review*, July 1995, pp. 13–28.

[7] Gullickson, "Measurement of productivity growth," *Monthly Labor Review*, July 1995, pp. 13–28.