Capital Formation and Productivity Convergence Over the Long Term

By EDWARD N. WOLFF *

*Catch-up in total factor productivity (*TFP*) among the "group of seven" was evident between 1870 and 1979, though much slower before 1938 than after 1950. Capital:labor ratios also converged over the long period, though the process was much stronger after 1960.* TFP *catch-up is found to be positively associated with capital:labor growth and strongest when capital intensity is growing most rapidly. The United States overtook the United Kingdom in technological leadership in 1900 when its capital:labor growth was more than three times higher. The steady deterioration in the United Kingdom's relative* TFP *since 1900 and the United States' since 1950 are both associated with low rates of capital formation. (JEL* O57, O30, J24, O40)

Recent studies have documented a convergence both in average labor productivity levels and in per capita income over the last century or so and particularly since the end of World War II among industrialized economies (see e.g., Moses Abramovitz [1979, 1986], Angus Maddison [1982, 1987], Gottfried Bombach [1985], and William Baumol [1986] for labor productivity statistics; Baumol and Wolff [1988] for GDP per capita; and Steve Dowrick and Duc-Tho Nguyen [1989] for total factor productivity). Abramovitz's (1986) and Baumol's (1986) results, in particular, highlight these trends. They found an almost perfect inverse relation between labor productivity levels in 1870 and the rate of labor productivity growth between 1870 and 1979 among 16 Organization for Economic Cooperation and Development (OECD) countries. In addition, the coefficient of variation in productivity levels, defined as the ratio of the standard deviation to mean productivity, fell from 0.48 in 1870 to 0.16 in 1979.

Abramovitz (1986) also investigated subperiods and found that labor productivity convergence was much slower in the period before World War II than after. Indeed, even in the postwar period, there is evidence from Abramovitz and from Baumol and Wolff (1988) that productivity convergence has slowed down during the 1970's, though this is disputed by Dowrick and Nguyen, who find parameter stability in their catch-up model between pre- and post-1973 periods when controlling for factor-intensity growth. Abramovitz also found that there were significant changes in leadership and the rank order of countries over time. Results of Bradford De Long (1988) show very little evidence of productivity convergence over the last century when the sample is no longer restricted to OECD countries. However, Baumol and Wolff, using the Robert Summers and Alan Heston (1988) sample, which covers countries at all levels of development, found convergence in real GDP per capita among the top third or so over the 1950–1981 period, though it was weaker than among OECD countries alone.

Explanations of the productivity catch-up almost all involve the so-called "advantages of backwardness," by which it is meant that much of the catch-up can be explained by the diffusion of technical knowledge from the leading economies to the more backward ones (see e.g., Alexander

*Department of Economics, New York University, New York, NY 10003. I thank the National Science Foundation, the Exxon Foundation, and the C. V. Starr Center for Applied Economics for support of the research. I also thank William Baumol, Moses Abramovitz, and four anonymous referees for their valuable suggestions.

Gerschenkron, 1952; Simon Kuznets, 1973). Indeed, the further an economy is from the technological frontier, the greater the rate of technical advance possible from such borrowing. However, being backward does not itself guarantee that a nation will catch up. Other factors must be present, such as strong investment (see Abramovitz [1979 p. 2] for a discussion of potential advances in productivity from capital accumulation), an educated work force, a suitable product mix, and developed trading relations with advanced countries. This paper investigates the role of capital formation in the process of productivity catch-up.

This study considers three hypotheses (which are not mutually exclusive) to account for the observed convergence in labor productivity levels among the advanced nations. The first is the "catch-up" hypothesis, which states that countries that lag furthest behind the leading countries in terms of technology level should exhibit the most rapid rate of growth in technology. This would also imply convergence in total factor productivity (TFP) levels, defined as the ratio of output to a weighed sum of labor and capital inputs, among nations. The second hypothesis is that the convergence in labor productivity levels has been due to narrowing of differences in factor intensities (capital:labor ratios) among industrialized countries.

The third hypothesis is that there are positive interactions between capital accumulation and technological advance. This deserves some comment. There are several avenues through which capital formation and total factor productivity growth may be associated. First, it is likely that substantial capital accumulation is necessary to put new inventions into practice and to effect their widespread employment. This association is often referred to as the "embodiment effect," since it implies that at least some technological innovation is embodied in capital. It is also consistent with the "vintage effect," which states that new capital is more productive than old capital per (constant) dollar of expenditure. If the capital stock data do not correct for vintage effects, then a positive correlation should be observed between the rate of technological gain and the change in the growth rate of capital.

A second avenue is that the introduction of new capital may lead to better organization, management, and the like. This may be true even if no new technology is incorporated in the capital equipment. A third avenue is through learning-by-doing (see Kenneth Arrow, 1962). Thus, technological advance should be correlated with the accumulation of capital stock. Fourth, potential technological advance may stimulate capital formation, because the opportunity to modernize equipment promises a high rate of return to investment. A fifth avenue is through the so-called Verdoorn or Kaldor effect, whereby investment growth may lead to a growth in demand and thereby to the maintenance of a generally favorable economic climate for investment. Such positive feedbacks may act cumulatively. These last four arguments do not lead to a specific functional relation between TFP growth and the rate of capital or capital:labor growth but do suggest a positive correlation between the two sets of variables.

In my analysis, it is not possible to distinguish among these various effects, and I will refer to them collectively as interaction effects or complementarities between capital accumulation and technological advance. Moreover, as is apparent, it is not possible to attribute causation one way or the other, since the influence between TFP growth and capital formation runs in both directions. However, it is possible to test for these interaction effects, and results will be reported below.[1]

The empirical analysis is limited to the "group of seven"—Canada, France, Germany, Italy, Japan, the United Kingdom, and the United States—over the 1870–1979 period, because of the availability of consistent data on total capital stock for this period provided in Maddison (1982). This sample is by no means representative and is

[1]Also, see Richard Nelson (1964), Kuznets (1973), Abramovitz and Paul David (1973), Bombach (1985), and Robert Solow (1988) for related discussions.

subject to many of the same criticisms made by De Long (1988) of the OECD samples.

Support is found for the three hypotheses. First, TFP levels converged among the group of seven over the 1870–1979 period. However, the pattern is far from uniform, with convergence much stronger after World War II than before, as Abramovitz (1986) found for labor productivity. Second, aggregate capital:labor ratios showed convergence over the long period, though the process was much stronger after 1960; before World War II, it is evident only when the United States, which surged ahead of the other countries between 1900 and 1938, is excluded from the sample. Technological advance and capital formation played about equal roles in labor productivity growth.

Third, the data show a positive correlation of 0.79 between the rate of TFP growth and that of the capital:labor ratio over the 1880–1979 period. Results, based on regression analysis and a vintage model, are somewhat mixed but generally support the existence of an interaction effect between technological advance and capital accumulation. The effect was strongest during the postwar period, when both capital:labor growth and the speed of technological catch-up were greatest. Overall, convergence in labor productivity levels is found to be a consequence of all three effects.

The next part of the paper provides evidence of convergence in productivity levels, and Section II presents statistics on growth in capital and changes in capital intensity over time. Section III considers the relation between capital formation and the rate of technological progress. Concluding remarks are made in the last section.

I. Productivity Catch-Up

The TFP level for country h is defined as the ratio of total output (Y^h) to a weighted average of labor input (L^h) and capital input (K^h)

$$(1)\quad \mathrm{TFP}^h = Y^h / \left[\alpha^h L^h + (1-\alpha^h) K^h\right]$$

where the labor input is measured by hours of work, the capital stock is measured by gross nonresidential fixed plant and equipment, and α^h is the wage share in country h.[2] Total factor productivity growth is based on the Divisia measure, ρ, defined as

$$(2)\quad \rho^h = \hat{Y}^h - \alpha^h \hat{L}^h - (1-\alpha^h)\hat{K}^h$$

where a superscript "hat" (^) indicates the relative rate of change (see Frank Gollup and Dale Jorgensen [1980] for a discussion of the Divisia index). The Tornqvist approximation based on average period shares is employed.[3]

The choice of the proper factor shares is debatable. Under the assumption that technology is the same across countries and that factor prices are equalized, as in the Heckscher-Ohlin model (see e.g., Edward Leamer, 1984) factor shares should be equal among countries, so that international average factor shares provide the best approximation. On the other hand, if technology differs among countries, then country-specific wage shares should be used. The results point to the latter choice. However, the only available data for the full 1870–1979 period are employee compensation (EC) and national income (NI) for the United Kingdom and the United States, so that factor shares are based on the average ratio of EC to NI in the two countries.[4]

[2] John Kendrick and R. Sato (1963) demonstrate that this index can be derived as a special case of the CES production function.

[3] Two other indexes were employed. First, the translog index of TFP level [see equation (4) in Section III] was used as an alternative to equation (1). Second, the time derivative of equation (1) was used as an alternative to the Divisia index. Results are similar to those based on (1) and (2) and are not reported here.

[4] For the postwar period, data availability is much greater, and therefore several alternative measures of factor shares were constructed, including the ratio of EC to GDP, the inclusion of a labor portion of entrepreneurial (self-employment income) in the wage share, and country-specific factor shares. In addition, net capital stock estimates were also available for all countries except Italy. Furthermore, since, productivity movements are sensitive to business-cycle fluctuations, the TFP index was also adjusted for capacity utilization, as

$$(1')\quad \mathrm{TFPU}^h = Y^h / \left[\alpha^h L^h + (1-\alpha^h) u^h K^h\right]$$

TABLE 1—TOTAL FACTOR PRODUCTIVITY (TFP) LEVELS, 1870–1979

	TFP (Index numbers, United States = 1.00 in 1950)[a]										
Country	1870	1880	1890	1900	1913	1929	1938	1950	1960	1970	1979
Canada	—	—	—	—	—	0.50	0.49	0.86	1.00	1.17	1.23
France	—	—	—	—	—	—	—	0.54	0.78	1.12	1.31
Germany	0.16	0.18	0.22	0.27	0.31	0.38	0.46	0.43	0.76	1.01	1.12
Italy	—	0.17	0.18	0.20	0.26	0.34	0.42	0.45	0.65	1.04	1.21
Japan	—	0.08	0.09	0.11	0.14	0.24	0.32	0.21	0.36	0.83	1.01
United Kingdom	0.28	0.32	0.36	0.40	0.44	0.53	0.57	0.72	0.85	1.05	1.15
United States	0.25	0.30	0.36	0.41	0.49	0.65	0.65	1.00	1.13	1.28	1.38
Five-country statistics (Germany, Italy, Japan, United Kingdom, and United States):											
CV[b]	—	0.43	0.43	0.42	0.38	0.34	0.24	0.48	0.33	0.14	0.10
Max/min[c]	—	4.10	3.89	3.66	3.47	2.74	2.04	4.70	3.11	1.55	1.37
Average/U.S.[d]	—	0.62	0.59	0.60	0.59	0.57	0.69	0.45	0.58	0.77	0.81
Seven-country statistics:											
CV[b]	—	—	—	—	—	—	—	0.42	0.29	0.12	0.09
Max/min[c]	—	—	—	—	—	—	—	4.70	3.11	1.55	1.37
Average/U.S.[d]	—	—	—	—	—	—	—	0.54	0.65	0.81	0.85

	Average annual rate of productivity growth								
	1880–1938			1950–1979			1880–1979		
Country	TFP (percentage)	Labor (percentage)	Ratio	TFP (percentage)	Labor (percentage)	Ratio	TFP (percentage)	Labor (percentage)	Ratio
Canada	—	—	—	1.44	2.58	0.56	—	—	—
France	—	—	—	3.04	4.64	0.66	—	—	—
Germany	1.20	1.86	0.65	3.33	5.52	0.60	1.56	2.66	0.59
Italy	0.58	1.80	0.32	3.09	4.99	0.62	1.36	2.59	0.52
Japan	1.32	2.52	0.52	4.17	6.92	0.60	1.62	2.98	0.54
United Kingdom	0.75	1.16	0.65	1.48	2.85	0.52	1.09	1.78	0.61
United States	0.77	1.88	0.41	1.36	2.30	0.59	1.37	2.26	0.60
Mean:	0.92	1.84	0.51	2.56	4.26	0.59	1.40	2.45	0.57

[a]TFP levels are computed according to equation (1). Output is measured by GDP, labor by hours worked, and capital by gross nonresidential fixed plant and equipment (net for Germany). Factor shares are based on the average ratio of employee compensation to national income for the United Kingdom and the United States over the 1870–1979 period.

[b]Coefficient of variation, defined as the ratio of the standard deviation to the mean.

[c]Ratio of the maximum to the minimum productivity level.

[d]Ratio of unweighted average productivity level of all countries except the United States to U.S. productivity level.

Table 1 shows computations of TFP levels for the period from 1870 to 1979.[5] It should be noted that the sample of countries diminishes as one goes further back in time because of data availability. The United Kingdom was the early leader in total factor productivity. The United States caught up to the United Kingdom by 1890 and led

where u is the capacity utilization rate, based on the utilization index for the manufacturing sector. Results did not materially differ from those reported here and are not shown.

[5]The primary data source on output, gross capital stock, and hours worked is Maddison (1982), in which problems of comparability of measures across countries are discussed. Estimates of GDP and man-hours for the 19th century are based on partial data. Many of the estimates are performed through backward interpolation of average growth rates. This has the effect of smoothing out the series and biasing the results toward convergence. Random errors of measurement at period end points will also likely bias the results in favor of convergence (see Abramovitz [1986] for a discussion of

thereafter. The United Kingdom remained in second place until 1950, when it was overtaken by Canada; by 1979, it had fallen to fifth (out of seven countries). Japan was last throughout the period, though its TFP relative to the United States increased from one-fourth in 1880 to three-fourths in 1979.

this point). Input measures do not adequately capture differences in natural resources, particularly land. This is particularly problematic for the early years (1870–1913), when the economies of these countries had a large agricultural sector. Because of the land:labor-ratio advantage of the United States and the declining share of agriculture in GDP over time of all seven countries, the technological gains of the United States relative to other countries will be *understated* by the TFP estimates. Differences in human capital are not reflected in the data. Differences in service-life assumptions, retirement patterns, depreciation schedules, and capital prices among countries will lead to inconsistencies in capital stock estimates among countries. Maddison attempted to standardize the estimates by benchmarking each national capital stock series to specially constructed 1976 estimates for each country, using international capital prices and the same assumptions with regard to service life and retirement patterns. Remaining errors in measurement will have the effect of overstating the variance of capital:labor ratios across countries and understating the variation of TFP relative to labor productivity. Also, see Abramovitz (1986) for further discussion of weaknesses in the long-term data.

Other data sources are as follows. Estimates of net capital stock are derived from Raymond Goldsmith (1985). The 1950 figures are from table 18 of Goldsmith; estimates for other years are based on individual country tables and geometric interpolation. Data on utilization rates are from the OECD's *Main Economic Indicators, 1960–1979* and David Coe and Gerald Holtham (1983). Data on wage shares are computed from the following sources: (i) data for 1950–1979 are from the United Nations' *Yearbook of National Accounts Statistics*, selected years, except for the 1950–1960 period in Italy; (ii) data for 1937–1950 and for 1950–1960 in Italy are from the International Labour Organization's *Yearbook of Labor Statistics*, various years; (iii) for Japan, data for 1920–1937 are from Kasushi Ohkawa and Henry Rosovsky (1973 pp. 316–7); (iv) for the United Kingdom, data for 1870–1938 are from Phyllis Deane and W. A. Cole (1964 p. 247); (v) for the United States, data for 1870–1938 are from D. Gale Johnson (1954); (vi) data on entrepreneurial income are from the United Nations' *Yearbook of National Accounts Statistics*, various years. The apportionment of entrepreneurial income into a wage and profit component is based on Johnson (1954), who estimated a 65-percent share for labor compensation and a 35-percent share for return on capital.

According to three indexes (the ratio of maximum to minimum TFP levels, the coefficient of variation, and the average TFP level of the other countries relative to the United States), there was only moderate convergence between 1880 and 1929 (particularly between 1880 and 1913). This is similar to labor productivity movements among the five countries.[6] The Depression years did bring some convergence in TFP levels, followed by a sharp increase in dispersion between 1938 and 1950. This was partly a consequence of the deleterious effect of World War II on German and Japanese productivity, which declined in absolute terms, but mainly due to a tremendous increase in U.S. productivity. Another indicator of catch-up is a negative correlation of TFP growth rates with initial TFP levels. These coefficients show the same pattern: -0.20 for 1880–1913, -0.33 for 1880–1929, -0.64 for 1880–1938, and -0.83 for 1880–1979.

The postwar period (1950–1979 here) provides a relatively good case study of the catch-up process, because it is the longest stretch of time unbroken by a major war or a depression. Over this period, the coefficient of variation fell by more than two-thirds, the ratio of maximum to minimum TFP level declined by about two-thirds, and average TFP relative to the United States rose from 0.54 to 0.85. Moreover, the correlation of TFP growth rates with initial TFP levels (in 1950) was -0.96.[7]

Results are also shown for average annual rates of both TFP and labor productivity growth. TFP growth averaged 1.4 percent per year over the 1880–1979 period,

[6]However, the results differ from Abramovitz's (1986) finding for labor productivity trends among 16 OECD countries. In particular, the coefficient of variation in labor productivity levels decreased from 0.51 in 1870 to 0.48 in 1880, 0.33 in 1913, and 0.29 in 1929. Thus, slow declines were observed for 1870–1880 and 1913–1929.

[7]Correlations were equally strong using the alternative measures of TFP introduced in footnote 4. Computations of correlation coefficients that exclude Japan were quite similar in magnitude. Correlations between TFP growth and the natural logarithm of initial TFP were even stronger.

and labor productivity growth averaged 2.5 percent per year. Japan led in both, while the United Kingdom was last. The ratio of TFP to labor productivity growth, a rough measure of the contribution of technical change to labor productivity growth, averaged 0.57, with the remaining portion due to capital deepening. There was relatively little variation among the five countries in the sample.

Over the 1880–1938 period, there were greater differences among countries. A comparison of the United Kingdom and the United States is revealing. Both experienced the same TFP growth. However, labor productivity growth was substantially lower in the United Kingdom, because of a much smaller growth in capital intensity. In fact, only a third of the United Kingdom's labor productivity growth was attributable to capital-deepening, in comparison to 60 percent for the United States. Over the postwar period, the ratio of TFP to labor productivity growth averaged 0.59, compared to 0.51 during 1880–1938, and there was less variation among countries.[8]

In sum, the period before World War II was one of moderate growth in both TFP and labor productivity and moderate catch-up in TFP levels. In contrast, the postwar period was characterized by strong growth in productivity and rapid convergence in productivity levels.

II. Capital Intensity

There are two apparently conflicting sets of results with regard to convergence in aggregate capital : labor ratios. According to the three summary measures shown in Table 2, there was slightly increasing disparity in capital:labor ratios before World War II and rapid convergence after 1960.[9] However, correlations between initial capital: labor ratio and its rate of growth show catch-up in capital intensity: −0.28 for 1880–1913, −0.59 for 1913–1938, 0.24 for 1938–1950 and −0.91 for 1950–1979. For the full 1880–1979 period, the correlation was −0.97. Thus, except for the period covering World War II, countries with lower initial levels of capital intensity experienced faster growth in their capital:labor ratio. The discrepancy is due to the very rapid growth in U.S. capital intensity between 1890 and 1938, by which time its capital:labor ratio was three times the average of the others. Indeed, when the United States is eliminated from the sample, the coefficient of variation in capital intensity shows a decline from 0.68 in 1880 to 0.37 in 1938.

The United Kingdom was the most capital-intensive in 1870 and 1880. The United States led in capital:labor growth during the 1880–1913 period and by 1890 was the most capital-intensive country, a position it held through 1970 (by 1979, Germany had become the most capital-intensive). U.S. capital-intensity growth was more than three times greater than the United Kingdom's between 1880 and 1913, which explains the emergence of the United States as the leader in labor productivity.

Three important relations become apparent from the data. First, there is a direct correspondence by period between the degree of capital-intensity catch-up and TFP convergence: strongest in 1950–1979, second strongest in 1913–1938, weakest in 1880–1913, and divergent in 1938–1950. Second, there is also a direct correspondence by period between TFP convergence and the average growth in capital intensity: highest in 1950–1979 (average capital:labor growth of 4.4 percent per year), next in 1913–1938 (2.2 percent), third in 1880–1913 (1.9 percent), and last in 1938–1950 (1.2 percent).[10] Third, countries with higher cap-

[8]Maddison (1987) computed a higher average ratio of 0.74 over the 1950–1973 period for six countries: France, Germany, Japan, the Netherlands, the United Kingdom, and the United States. The difference is mainly due to Maddison's higher labor shares.

[9]Results for the postwar period are quite similar for the ratio of net capital stock to hours of work.

[10]A regression of the coefficient of variation of TFP levels on the average capital:labor growth rate for each of ten periods yields a highly significant negative coefficient on capital:labor growth.

TABLE 2—CAPITAL:LABOR RATIOS, 1870–1979

	Ratio of gross capital to hours (index numbers, standardized so that GDP per hour = 1.00 for United States in 1950)[a]										
Country	1870	1880	1890	1900	1913	1929	1938	1950	1960	1970	1979
Canada	—	—	—	—	—	1.34	1.46	1.89	2.82	3.60	4.45
France	—	—	—	—	—	—	—	1.22	1.58	2.60	4.08
Germany	0.30	0.38	0.47	0.59	0.74	0.87	0.89	0.99	1.46	2.87	5.12
Italy	—	0.14	0.18	0.21	0.30	0.46	0.68	0.75	0.98	1.95	3.23
Japan	—	0.06	0.07	0.08	0.12	0.23	0.28	0.32	0.40	1.18	2.55
United Kingdom	0.48	0.55	0.56	0.62	0.72	0.92	0.93	1.11	1.35	2.17	3.12
United States	0.41	0.52	0.60	0.87	1.23	1.75	2.14	2.41	3.15	4.06	4.89
Five-country statistics (Germany, Italy, Japan, United Kingdom, and United States):											
Mean	—	0.33	0.38	0.47	0.62	0.85	0.99	1.12	1.47	2.45	3.78
CV[b]	—	0.59	0.57	0.61	0.62	0.62	0.63	0.63	0.63	0.40	0.27
Average/U.S.[c]	—	0.54	0.54	0.43	0.38	0.36	0.32	0.33	0.33	0.50	0.72
Seven-country statistics											
Mean	—	—	—	—	—	—	—	1.24	1.68	2.63	3.92
CV[b]	—	—	—	—	—	—	—	0.52	0.54	0.35	0.23
Average/U.S.[c]	—	—	—	—	—	—	—	0.43	0.45	0.59	0.77

	Average annual growth rates (percentages)				
Country	1880–1913	1913–1938	1938–1950	1950–1979	1880–1979
Canada	—	—	2.17	2.96	—
France	—	—	—	4.17	—
Germany	2.07	0.69	0.92	5.67	2.64
Italy	2.26	3.27	0.75	5.05	3.15
Japan	1.92	3.57	1.08	7.12	3.76
United Kingdom	0.83	1.02	1.47	3.56	1.75
United States	2.61	2.23	0.98	2.44	2.27
Mean:	1.94	2.16	1.23	4.42	1.50
SD:	0.60	1.16	0.47	1.52	0.38
CV:[b]	0.31	0.54	0.39	0.34	0.26

[a]The labor input is measured by hours worked and capital by gross nonresidential fixed plant and equipment (net for Germany). Calculations of the mean, standard deviation, and coefficient of variation are based on countries in the sample with the relevant data.
[b]Coefficient of variation, defined as the ratio of the standard deviation to the mean.
[c]Ratio of unweighted average for all countries except the United States to the U.S. value.

ital:labor growth generally had higher TFP growth. The rank order is identical for the postwar period: Japan (annual capital:labor growth of 7.1 percent), Germany (5.7 percent), Italy (5.1 percent), France (4.2 percent), United Kingdom (3.6 percent), Canada (3.0 percent), and the United States (2.4 percent). For the whole 1880–1979 period, Japan was first in capital:labor growth, followed by Italy, Germany, the United States, and the United Kingdom. Except for a reversal between Italy and Germany, the rank order was identical to that of TFP growth. These empirical findings suggest the existence of interaction effects between capital growth and technology growth.

III. Interactions Between Capital Accumulation and Productivity Growth

I use a standard growth-accounting framework to assess the extent to which convergence in technology levels is associated with capital accumulation through interaction effects between the two. Formally, assume that for each country h there is a Cobb-Douglas value-added production function:

$$(3)\quad \ln Y^h = \zeta^h + \alpha \ln L^h + (1-\alpha)\ln K^h.$$

The parameter ζ^h is country-specific and indicates country h's technology level. The output elasticity of labor, α, is assumed to be the same across countries. If factors are paid their marginal products, then the output elasticity is equal to labor's distributional share. This study will use the cross-country (unweighted) average of labor's share as the estimate of α.

Next, define the translog index of TFP level:

$$(4)\quad \ln \mathrm{TFP}^h = \ln Y^h - \alpha \ln L^h - (1-\alpha)\ln K^h$$

which is consistent with the Divisia index of TFP growth. Comparison of equation (4) with equation (3) reveals that this measure of TFP level is implicitly based on a Cobb-Douglas form for the production function. Moreover, let the United States be the benchmark country, and define the following:

π^h: ratio of country h's labor productivity to U.S. labor productivity;
τ^h: ratio of country h's technology level to U.S. technology level;
κ^h: ratio of country h's capital:labor ratio to U.S. capital:labor ratio.

Equations (3) and (4) then imply that

$$(5)\quad \ln \pi^h = \ln \tau^h + (1-\alpha)\ln \kappa^h.$$

Differentiating this with respect to time yields

$$(6)\quad \hat{\pi}^h = \hat{\tau}^h + (1-\alpha)\hat{\kappa}^h.$$

Capital formation may be expected to exert two distinct effects on labor productivity. First, by raising the capital:labor ratio, it will increase labor productivity even if there is no advance in technology in use [equation (6)]. Second, through interactions with technology advance, accumulation may be associated with gains in productivity over and above capital deepening. Three approaches for testing the interaction effect are considered here.

A. *Correlation Between TFP and Capital:Labor Growth*

The first and most direct test is to determine whether there is a positive correlation between $\hat{\tau}$ and $\hat{\kappa}$. Though this approach is not consistent with a strict vintage model, it probably captures the general set of interactions between the two variables, as discussed in the introduction. The correlation coefficient was 0.08 for 1880–1913, 0.37 for 1913–1938, 0.56 for 1938–1950, 0.95 for 1950–1979 and 0.79 for the whole 1880–1979 period.[11] These results are generally consistent with the hypothesis that high rates of technical advance are associated with high rates of capital formation. However, they indicate that the relation was considerably stronger after World War II than during the prewar years.

B. *Regression Analysis*

A second approach uses a regression framework. Two basic specifications are employed:

$$(7\mathrm{a})\quad \hat{\tau}_t^h = b_0 + b_1\tau_t^h + b_2\hat{\kappa}_t^h + \varepsilon_t^h$$

$$(7\mathrm{b})\quad \hat{\tau}_t^h = b_0 + b_1\tau_t^h + b_2\,\Delta\hat{\kappa}_t^h + \varepsilon_t^h$$

where τ_t^h is country h's (translog) TFP relative to the United States at the start of each period, $\Delta\hat{\kappa}_t^h \equiv \hat{\kappa}_t^h - \hat{\kappa}_{t-1}^h$, and ε is a stochastic error term. In some specifications, country dummy variables (except the United Kingdom) are included to control for country-specific effects, such as the degree of trade openness, culture, and government policy. In some, period dummy variables are also included to allow TFP growth to vary by period (e.g., in response to unevenness in the flow of new technology or inventions).

[11] Other periods were used in the analysis, including 1880–1900, 1900–1913, 1900–1929, 1913–1929, 1929–1938, and 1929–1950, with similar results.

TABLE 3—REGRESSIONS OF RELATIVE PRODUCTIVITY GROWTH ($\hat{\tau}$) ON RELATIVE PRODUCTIVITY LEVEL AND CAPITAL:LABOR GROWTH AND INTENSITY, 1880–1979

Independent variable	Regression 1	2	3	4	5	6	7
Constant	−0.011*	−0.011*	−0.006	−0.008	−0.001	−0.011	−0.002
	(2.55)	(2.55)	(1.42)	(1.47)	(0.21)	(1.64)	(0.34)
τ	−0.042**	−0.039**	−0.042**	−0.080**	−0.085**	−0.078**	−0.073**
	(3.94)	(3.60)	(3.45)	(5.72)	(5.07)	(5.00)	(4.04)
$\hat{\kappa}$		0.130		0.189*		0.395**	
		(1.15)		(2.09)		(3.47)	
$\Delta\hat{\kappa}$			0.008		0.003		0.024*
			(0.65)		(0.79)		(2.17)
Country dummies	no	no	no	yes	yes	yes	yes
Period dummies	no	no	no	no	no	yes	yes
R^2:	0.27	0.29	0.28	0.53	0.49	0.81	0.83
Adjusted R^2:	0.25	0.26	0.24	0.44	0.37	0.71	0.72
SE:	0.017	0.017	0.018	0.015	0.016	0.011	0.011
D-W[a]:	2.31	2.47	2.57	2.19	2.25	2.14	2.01
Sample size:	44	44	38	44	38	44	38
d.f.:	42	41	35	36	32	28	22

Notes: Numbers in parentheses below the coefficient estimates are t statistics. Key: τ^h = ratio of country h's technology level to U.S. technology level; κ^h = ratio of country h's capital:labor ratio to the U.S. capital:labor ratio. Computations are based on gross capital stock (net for Germany) and national income-based factor shares averaged between the United Kingdom and the United States. For regressions 1, 2, 4, and 6, observations are for Germany, Italy, Japan, and the United Kingdom for nine periods: 1880–1890, 1890–1900, 1900–1913, 1913–1929, 1929–1938, 1938–1950, 1950–1960, 1960–1970, and 1970–1979; Canada for 1929–1938, 1938–1950, 1950–1960, 1960–1970, and 1970–1979; and France for 1950–1960, 1960–1970, and 1970–1979; for regressions 3, 5, and 7, the 1880–1890 observation is excluded.

[a]Durbin-Watson statistic, based on observations ordered within country over time.

*Significant at the 5-percent level; **significant at the 1-percent level.

The sample for (7a) consists of six countries (excluding the United States) for each of nine time periods (with available data): 1880–1890, 1890–1900, 1900–1913, 1913–1929, 1929–1938, 1938–1950, 1950–1960, 1960–1970, and 1970–1979; the sample size is 44. The sample for (7b) is the same, except that the 1880–1890 observation is excluded; the sample size is 38.

Two tests are made of the interaction hypothesis. The first [specification (7a)] posits a positive association between the rate of growth of relative productivity, $\hat{\tau}^h$, and the *rate of growth* of the relative capital:labor ratio, $\hat{\kappa}^h$. This is consistent with the general formulation of the interaction effect. The second [specification (7b)] posits a positive relation between $\hat{\tau}_i^h$ and the *change* in $\hat{\kappa}^h$. The latter is consistent with the strict vintage model, since the change in the average age of the capital stock depends on the *acceleration* in the rate of capital growth (see Nelson, 1964). Also, as is implicit in the two specifications, the catch-up hypothesis is tested (a negative coefficient on τ^h).

Results for the interaction hypothesis, shown in Table 3, are generally supportive. Coefficient estimates for relative capital:labor growth are all positive (columns 2, 4, and 6). The coefficient estimate for $\hat{\kappa}$ is not significant when no country or period dummy variables are included, significant at the 5-percent level when country dummies are included, and significant at the 1-percent level when both sets are included. The latter is perhaps the most revealing result, since it suggests that it is the residual variation in TFP growth, after country- and time-specific effects are removed, that is most strongly correlated with the variation in capital:labor growth.

The results for $\Delta\hat{\kappa}_t^h$ (columns 3, 5, and 7) are all positive, as predicted, but insignificant except when both country and time dummy variables are added, in which case it is statistically significant at the 5-percent level. Thus, (7a) provides a better fit to the data.[12] The results also confirm the catch-up hypothesis, at the 1-percent significance level, for this (highly selective) sample of countries.

The F test for the inclusion of the country dummy variables suggests that there are country-specific effects—economic, cultural, and institutional—that play an important role in productivity growth. Dummy variables (relative to the United Kingdom) are not significant for Canada and France in equation (7a) but are statistically significant at the 1-percent level and negative for Germany, Italy, and Japan. In other words, once relative backwardness and the rate of capital:labor growth are accounted for, Germany, Italy, and Japan had lower TFP growth than the United Kingdom. My results also held for the postwar period and differ from those of Dowrick and Nguyen, who found higher than predicted TFP growth for France, Germany, and Japan during 1950–1985, once these two factors were controlled. The reason for the difference in results is not readily apparent, though Dowrick and Nguyen use a different sample of countries and base their estimate of capital stock on investment flow data.

Moreover, the F test for the inclusion of period dummy variables is significant at the 1-percent level for each specification with country dummy variables. The only two period dummies that are statistically significantly different at the 5-percent level from 1970–1979 are 1929–1938, which is positive (a consequence of low investment rates during the Depression), and 1938–1950, which is negative (from the effects of World War II on output).

Finally, when the regressions are performed separately for prewar data (1880–1938) and postwar data (1950–1979), results are much stronger for the latter. In particular, for equation (7a), with country dummy variables, the coefficient of $\hat{\kappa}$ is 0.306, which is significant at the 1-percent level, and the R^2 statistic is 0.95 for the 1950–1979 data.[13] For the 1880–1938 data; the coefficient of $\hat{\kappa}$ is 0.088, which is not statistically significant, and the R^2-statistic is 0.46. An F test (or "Chow test" from Gregory Chow [1960]) on structural change between the 1880–1938 data and the 1950–1979 data is statistically significant at the 1-percent level. The results are consistent with the correlation coefficients between TFP growth and capital:labor growth by period. I will have more to say about this in the conclusion.[14]

[12]The variable $\hat{\gamma}_t^h \equiv \hat{K}_t^h - \hat{K}_t^{US}$ is also used in place of $\hat{\kappa}_t^h$ in (7a) and $\Delta\gamma_t^h$ in place of $\Delta\hat{\kappa}_t^h$ in (7b). The former is insignificant except when both country and time dummy variables are added, in which case it is statistically significant at the 5-percent level. The latter is not statistically significant in any form. The interaction effect is more strongly related to changes in capital intensity than to changes in total capital stock.

[13]One might assume at first glance that the postwar results are dominated by the German and Japanese reconstruction. However, when two interactive terms, $\hat{\kappa}\times$DUMGER and $\hat{\kappa}\times$DUMJAP, are included in the specification, $\hat{\kappa}$ remains significant at the 1-percent level.

[14]Additional tests were performed for both the full sample and the postwar sample. First, the observations were ordered by time within each country in order to test for autocorrelation. The Durbin-Watson statistics, shown in Table 3, all fall within the critical range (5-percent level), except one in the uncertainty range. Second, standard heteroscedasticity tests were performed for each regression equation for τ_t^h and $\hat{\kappa}_t^h$ or κ_t^h, where appropriate. The test results are all insignificant at the 5-percent level. Third, Ramsey RESET functional-form tests were performed for the square and cube of the predicted value of the dependent variable, with no significant results at the 5-percent level. For column 6 of Table 3, the $F_{[2,\,39]}$ statistic is 2.65, compared to a critical value of 3.23 at the 5-percent level. Fourth, an endogeneity test was performed for $\hat{\kappa}_t^h$ or κ_t^h, where appropriate, by first regressing $\hat{\kappa}_t^h$ on initial TFP and initial capital:labor ratio or κ_t^h on initial TFP and capital:labor growth, and then including the residual from this equation in the estimating equation. For column 6 of Table 3, the t statistic for the estimated residual is 1.1 and for column 7 the t statistic is 0.9. Two other specifications were also used:

$$\text{(7c)} \qquad \hat{\rho}_t^h = b_0 + b_1\tau_t^h + b_2\hat{k}_t^h + \varepsilon_t^h$$

$$\text{(7d)} \qquad \hat{\rho}_t^h = b_0 + b_1\tau_t^h + b_2\Delta\hat{k}_t^h + \varepsilon_t^h.$$

C. *Vintage Capital*

A third approach is to construct a vintage model of productivity growth, which relates the level of productivity not only to the level of the capital stock but also to the age distribution of the capital stock. To simplify, suppose that this year's capital investment is s percent more productive than last year's and that the parameter s is constant over time. Let $\bar{A}^h$ be the average age of country h's capital stock. Then,

$$(8)\quad \ln Y^h = \zeta^h + \alpha \ln L^h + (1-\alpha)\ln K^h - (1-\alpha)s^h\bar{A}^h.$$

The average age of the capital stock is estimated from capital-stock data for 1870, 1880, 1890, 1900, 1913, 1929, 1938, 1950, 1960, 1970, and 1979. It is assumed that the service life is 50 years and that the average age of the capital stock was 25 years in 1870. Estimates are not provided for Canada or France, because the capital-stock series are not long enough.

Results on average age are shown in Table 4. Capital-stock age moves inversely with changes in the rate of growth of the capital stock. If growth accelerates, the average age of the capital stock declines. Changes in the rate of growth of the capital stock are positively associated with the actual rates of growth of the capital stock (the correlation coefficient is 0.60). The average age for the five countries declined from 23 years in 1880 to 21 years in 1913, rose steadily to 28 years in 1950, then rapidly declined to 15 years in 1979. It is also interesting that the standard deviation of capital-stock age increased between 1880 and 1938. Over the postwar period, it remained relatively constant, except for a drop in 1960. This is true despite the convergence in capital:labor ratios after 1960.

The United States had by far the newest capital stock from 1880 to 1913 (one-third younger than the other four countries in 1900), a consequence of its high rate of capital growth. U.S. capital stock aged relative to the other countries from 1900 onward, and by 1979 it was 13-percent older than the that of other countries. From 1929 onward, Japan had the youngest capital stock; in 1979, its average age was two-thirds that of its nearest rival, Germany, and 0.58 that of the United States. In contrast, the United Kingdom had the oldest capital stock, a position it maintained for 100 years. In fact, in 1900, the U.K. capital stock was 70-percent older than that of the United States.

From (6) and (8) and with the added assumption that s is equal across countries, it follows that

$$(9)\quad \hat{\pi}^h = \hat{\tau}^h + (1-\alpha)\kappa^h - (1-\alpha)s\Lambda^h$$

where $\Lambda^h \equiv d\bar{A}^h/dt - d\bar{A}^{\mathrm{US}}/dt$, the difference in the *rate of change* in capital-stock age between country h and the United States (see Nelson, 1964). I also estimated the following regression equation:

$$(10)\quad \hat{\tau}_t^h = b_0 + b_1\tau_t^h + b_2\Lambda_t^h + \varepsilon_t^h.$$

The results for Λ^h are all negative, as predicted, and significant at the 1-percent level when no dummy variables are included ($R^2 = 0.41$) and when country dummy variables are included ($R^2 = 0.55$). The estimated value of s, on the basis of the first two forms, is 0.0082.[15]

D. *Capital:Output Constancy*

A constant capital:output ratio within countries can also lead to a positive interaction effect between TFP growth and the growth in the capital:labor ratio. It follows from this that the correlation between country TFP growth (ρ^h) and the growth in

These differ from (7a) and (7b) in using actual country TFP and capital:labor growth rates instead of relative rates. The sample also includes data from the United States. Results are similar to those reported in Table 3.

[15]The variable Λ^h is significant at only the 10-percent level when both country and time dummy variables are added, as a result of the high multicollinearity of Λ^h with time. A simple regression of Λ^h on the eight time dummy variables yields an R^2 of 0.58.

TABLE 4—AVERAGE AGE OF CAPITAL STOCK AND CAPITAL:OUTPUT RATIOS, 1870–1979

A. Average age of capital stock[a]

Country	1870	1880	1890	1900	1913	1929	1938	1950	1960	1970	1979
Germany	—	23.0	21.9	20.4	20.0	27.3	28.7	30.9	19.4	14.4	15.3
Italy	—	24.3	22.9	24.2	21.9	22.8	21.5	25.9	21.2	16.4	15.8
Japan	—	24.6	25.9	24.3	20.5	16.9	18.4	23.4	19.6	10.7	10.0
United Kingdom	—	25.6	27.1	27.0	25.7	28.5	30.1	31.4	24.8	19.3	19.2
United States	—	19.5	18.4	15.8	16.5	20.3	25.5	26.7	22.7	19.0	17.3
Mean:	—	23.4	23.2	22.3	20.9	23.2	24.8	27.7	21.5	16.0	15.5
SD:	—	2.1	3.1	3.9	3.0	4.3	4.4	3.1	2.0	3.2	3.1
Average/U.S.[b]:	—	1.25	1.33	1.52	1.33	1.18	0.97	1.04	0.93	0.80	0.87

B. Gross capital:GDP ratio (1970 U.S. prices)[b]

Country	1870	1880	1890	1900	1913	1929	1938	1950	1960	1970	1979
Canada	—	—	—	—	—	3.23	3.54	2.41	2.64	2.56	2.69
France	—	—	—	—	—	—	—	2.80	2.34	2.24	2.44
Germany	2.96	3.24	3.20	3.17	3.33	3.11	2.57	3.01	2.29	2.64	3.14
Italy	—	1.35	1.65	1.70	1.77	1.99	2.27	2.31	1.99	2.02	2.35
Japan	—	1.30	1.18	1.19	1.36	1.53	1.39	2.33	1.65	1.80	2.47
United Kingdom	2.56	2.49	2.25	2.18	2.28	2.29	2.15	1.97	1.92	2.16	2.42
United States	2.51	2.49	2.40	2.87	3.13	3.04	3.47	2.41	2.48	2.48	2.51
Mean:[c]	—	2.17	2.14	2.22	2.37	2.39	2.37	2.41	2.06	2.22	2.58
SD:	—	0.75	0.87	0.97	1.04	1.01	1.14	0.91	0.85	0.87	0.98

C. Average annual growth rates in capital:output ratios (percentages)

Country	1880–1938	1950–1979	1880–1979
Canada	—	0.38	—
France	—	−0.47	—
Germany	−0.40	0.15	−0.03
Italy	0.89	0.06	0.56
Japan	0.12	0.20	0.65
United Kingdom	−0.25	0.71	−0.03
United States	0.57	0.14	0.01
Mean:[b]	0.19	0.25	0.23
SD:[b]	0.49	0.23	0.31

[a]Average age is estimated from capital-stock data for 1870, 1880, 1890, 1900, 1913, 1929, 1938, 1950, 1960, 1970, and 1979. It is assumed that the service life is 50 years and that the average age of the capital stock was 25 years in 1870.

[b]Ratio of unweighted average ages for all countries except the United States to the U.S. age.

[c]The mean is the unweighted average for Germany, Italy, Japan, the United Kingdom, and the United States; the standard deviation is based on the same five countries.

the country capital:labor ratio ($\hat{k}^h \equiv \hat{K}^h - \hat{L}^h$) will be 1.0, even if technical change is disembodied. The result follows directly from (2) that, if $\hat{Y} = \hat{K}$, then

$$\rho_t^h = \alpha \hat{k}_t^h \tag{11}$$

or, equivalently,

$$\hat{\tau}_t^h = \alpha \kappa_t^h . \tag{12}$$

There are several theoretical justifications for this position. For example, in a Solow growth model, with a Cobb-Douglas production function with disembodied technical change such as (3), then in steady-state equilibrium the capital:output ratio will be constant (see Solow, 1956).

There are three testable implications of this model. First, capital:output ratios should be constant over time. However, results in panels B and C of Table 4 indicate that country capital:output ratios have changed over long periods, such as for Italy and the United States for 1880–1938; Canada, France, and the United Kingdom for the 1950–1979 period; and Italy and Japan over the 1880–1979 period. On average, capital:output ratios trended upward between 1880 and 1979. Moreover, the standard deviation of capital:output growth rates does indicate noticeable differences in the experiences of the five countries. However, changes in capital:output ratios have been considerably less than those for capital:labor ratios.[16]

Second, the correlation coefficient between TFP growth and the growth in the capital:labor ratios should be unity. The cross-country correlation coefficients were 0.08 for 1880–1913, 0.37 for 1913–1938, 0.56 for 1938–1950, 0.95 for 1950–1979, and 0.79 for 1880–1979. Thus, except for the postwar period, the correlation coefficients are much lower than this model would predict.

Third, from (12), the regression coefficient of $\hat{\kappa}$ in equation (7a) should equal the mean wage share, which for this sample was 0.598. I performed t tests for $\hat{b}_2 = 0.598$ on the basis of the three sets of regression results reported in Table 3 for the 1880–1979 period, and the nulls were rejected at the 1-percent level (one-tail test) in two cases and at the 5-percent level (one-tail test) in the third case. It was also rejected at the 1-percent level for the regression on postwar data with country dummy variables. These results suggest that the finding of a positive interaction effect cannot be simply ascribed to capital:output constancy.

E. *Increasing Returns to Capital*

Paul Romer (1986) has argued that increasing returns to capital and externalities from new knowledge development may account for rising worldwide productivity growth. This argument is based on the finding that labor productivity growth has been increasing over the long run, from 1770 to 1979. Romer argued that the rising world productivity growth may be due, in part, to the increasing returns to scale. It is difficult to discriminate directly between this model and the interaction hypothesis. A simple procedure is to replace $\hat{\kappa}_t^h$ with κ_t^h, the relative *level* of capital intensity in country h at time t (or γ_t^h, the relative level of capital stock) in equation (7a). Country and period dummy variables are also included in alternative specifications. The estimated coefficients of κ_t^h (and γ_t^h) are all statistically insignificant. Jess Benhabib and Boyan Jovanovic (1991), using U.S. aggregate data and the Summers-Heston sample, also find little evidence to support externalities to capital in a modified Romer model.

IV. Concluding Remarks

It is illuminating to recast the results in an historical frame. In 1880, the United Kingdom was the leading nation in terms of productivity and capital intensity, and the United States was second, while Italy and Japan were still in the earliest stages of industrialization. Between 1880 and 1938, despite two major depressions and a world war, modest convergence occurred in both TFP and labor productivity among the countries in the sample. The United States had by far the highest growth in capital intensity and, by 1938, had the newest capital stock, the highest capital:labor ratio (three times the average of the other countries), and the highest TFP level (45-percent greater than the average of the other countries). The United Kingdom was last in capital:labor growth and, by 1938, had slipped to third in terms of capital intensity and second in terms of TFP.

The 1938–1950 period, dominated by World War II, saw the United States surge ahead of the rest of the countries in terms of technological leadership. By 1950, the TFP level in the United States was more than twice the average of the other coun-

[16] However, it should be noted that the capital:output ratios have not been adjusted for changes in capacity utilization. Such an adjustment may reduce the variability in the estimated capital:output ratio over time.

tries. Moreover, absolute declines in TFP levels were recorded for Germany and Japan.

The postwar period, from 1950 to 1979, was characterized by very strong convergence in TFP, labor productivity, and capital intensity among the group of seven. Part of this process was due to the postwar recovery of Germany and Japan. However, this was also a period characterized by historically unprecedented high rates of TFP growth, labor productivity growth, and capital:labor growth. The United States maintained its technology leadership, but its relative position dwindled from more than twice the average of the other countries to a 22-percent differential. The United States had the lowest rate of capital:labor growth, and by 1979 its capital stock was 15-percent older than the other countries' and 73-percent older than Japan's.

In summary, the emergence of the United States as the technological leader in 1900 and the widening gap between the United States and rest of the world through 1950 coincides with a very high rate of capital:labor growth, its dominance in terms of capital intensity, and its new capital vintages. Its dwindling leadership position during the postwar period is coincident with low capital:labor growth and the aging of its capital stock. The loss of technological leadership by the United Kingdom after 1890 and the almost continuous slippage in its relative position thereafter is associated with a low rate of domestic investment and the relative aging of its capital stock.

Finally, the rate of catch-up of individual-country technology levels was positively associated with the rate of growth of the capital:labor ratios. However, the strength of this association varied over time and was strongest after World War II. Indeed, the regression results with the prewar data yield a positive but statistically insignificant interaction effect. These results are consistent with the results of Abramovitz (1986), who found sluggish convergence in labor productivity before World War II and rapid convergence after. He attributed the difference to the lack of "social capability," low educational levels, and inadequate industrial and financial organization before World War I; between 1913 and 1950, the process was interrupted by two world wars and the Great Depression; and only after 1950 was the process rapid and smooth, because all the elements for the catch-up process were in place.

A strong interaction effect appears to occur when inhibitions to growth are eliminated. Such a period is characterized by high (average) productivity growth, a high rate of capital formation, a large initial dispersion of technology levels, and rapid catch-up in technology, as characterized the years from 1950 to 1979. The interaction effect is likely to be weak when impediments to growth are present or when differences in technology levels among countries are small.

REFERENCES

Abramovitz, Moses, "Rapid Growth Potential and its Realization: The Experience of Capitalist Economies," in Edmond Malinvaud, ed., *Economic Growth and Resources*, Proceedings of the Fifth World Congress of the International Economic Association, Vol. 1, London: Macmillan, 1979, pp. 1–30.

______, "Catching Up, Forging Ahead, and Falling Behind," *Journal of Economic History*, June 1986, *46*, 385–406.

______ **and David, Paul A.,** "Reinterpreting Economic Growth: Parables and Realities," *American Economic Review*, May 1973 (*Papers and Proceedings*), *63*, 428–39.

Arrow, Kenneth, "The Economic Implications of Learning by Doing," *Review of Economic Studies*, June 1962, *29*, 155–73.

Baumol, William J., "Productivity Growth, Convergence, and Welfare: What the Long-Run Data Show?" *American Economic Review*, December 1986, *76*, 1072–85.

______ **and Wolff, Edward N.,** "Productivity Growth, Convergence, and Welfare: Reply," *American Economic Review*, December 1988, *78*, 1155–9.

Benhabib, Jess and Jovanovic, Boyan, "Externalities and Growth Accounting," *Ameri-*

can Economic Review, March 1991, *81*, 82–113.

Bombach, Gottfried, *Post-War Economic Growth Revisited*, Amsterdam: North-Holland, 1985.

Chow, Gregory C., "Tests of Equality between Sets of Coefficients in Two Linear Regressions," *Econometrica*, July 1960, *28*, 591–605.

Coe, David and Holtham, Gerald, "Output Responsiveness and Inflation: An Aggregate Study," *OECD Economic Studies*, Autumn 1983, *1*, 94–145.

Deane, Phyllis and Cole, W. A., *British Economic Growth, 1688–1959: Trends and Structure*, Cambridge: Cambridge University Press, 1964.

De Long, Bradford, "Productivity Growth, Convergence, and Welfare: Comment," *American Economic Review*, December 1988, *78*, 1138–54.

Dowrick, Steve and Nguyen, Duc-Tho, "OECD Comparative Economic Growth 1950–85: Catch-Up and Convergence," *American Economic Review*, December 1989, *79*, 1010–31.

Gerschenkron, Alexander, "Economic Backwardness in Historical Perspective," in Bert F. Hoselitz, ed., *The Progress of Underdeveloped Areas*, Chicago: University of Chicago Press, 1952, pp. 3–29.

Goldsmith, Raymond W., *Comparative National Balance Sheets* Chicago: University of Chicago Press, 1985.

Gollop, Frank M. and Jorgensen, Dale W., "U.S. Productivity Growth by Industry, 1947–73," in John W. Kendrick and Beatrice N. Vaccara, eds., *New Developments in Productivity Measurement and Analysis*, Chicago: University of Chicago Press, 1980, pp. 17–124.

Johnson, D. Gale, "The Functional Distribution of Income in the United States, 1850–1952, *Review of Economics and Statistics*, May 1954, *36*, 175–82.

Kendrick, J. and Sato, R., "Factor Prices, Productivity, and Economic Growth," *American Economic Review*, December 1963, 53, 974–1003.

Kuznets, Simon, *Population, Capital, and Growth: Selected Essays*, New York: Norton, 1973.

Leamer, Edward E., *Sources of International Comparative Advantage*, Cambridge, MA: MIT Press, 1984.

Maddison, Angus, *Phases of Capitalist Development*, Oxford: Oxford University Press, 1982.

______, "Growth and Slowdown in Advanced Capitalist Economies: Techniques of Quantitative Assessment," *Journal of Economic Literature*, June 1987, *25*, 649–706.

Nelson, Richard R., "Aggregate Production Functions and Medium-Range Growth Projections," *American Economic Review*, September 1964, *54*, 575–605.

Ohkawa, Kasushi and Rosovsky, Henry, *Japanese Economic Growth: Trend Acceleration in the Twentieth Century*, Stanford, CA: Stanford University Press, 1973.

Romer, Paul M., "Increasing Returns and Long-Run Growth," *Journal of Political Economy*, October 1986, *94*, 1002–37.

Solow, Robert M., "Contribution to the Theory of Economic Growth," *Quarterly Journal of Economics*, February 1956, *70*, 65–94.

______, "Growth Theory and After," *American Economic Review*, June 1988, *78*, 307–17.

Summers, Robert and Heston, Alan, "A New Set of International Comparisons of Real Product and Prices: Estimates for 130 Countries, 1950–1985," *Review of Income and Wealth*, March 1988, *34*, 1–26.

International Labor Organization, *Yearbook of Labor Statistics*, Geneva: International Labour Office, various issues.

OECD Statistical Division, *Main Economic Indicators, 1960–1979*, Paris: Organization for Economic Cooperation and Development, June 1980.

United Nations, *Yearbook of National Accounts Statistics*, New York: United Nations, various years.