The Productivity Slowdown: The Culprit at Last? Follow-Up on Hulten and Wolff

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Charles R. Hulten's (1992) article suggested that very little of the productivity slowdown of the 1970's could be attributed to capital-embodied technical change. Hulten estimated that about 20 percent of total technical change (what he termed the "residual growth of quality-adjusted output") in U.S. manufacturing over the period from 1949 to 1983 could be ascribed to embodied technical change in machinery and equipment. However, he found very little difference in the contribution of embodied technical change to total technical change between the periods 1949–1973 and 1974–1983, the slowdown period.

In my paper (Wolff, 1991), I found a very significant vintage effect, estimated by the change in the average age of the capital stock. My data, drawn from Angus Maddison (1982), covered the G-7 countries over the period 1880–1979 and were based on figures for total capital (structures, machinery, and equipment) and for the entire economy. These results suggested that embodied technical change played a significant role in the productivity falloff of the 1970's.

In this paper, I use more recent data for six OECD countries (France, Germany, Japan, the Netherlands, the United Kingdom, and the United States) compiled by Angus Maddison (1991, 1993a, b) and focus on the period from 1950 to 1989. I find here that the vintage effect is, indeed, a very strong determinant of the post-1973 productivity slowdown among OECD countries, explaining on average about two-fifths of the slowdown. The effect varies among countries, from a low of 23 percent in Japan to 69 percent in France. For the United States, the vintage effect appears to account for a little over half of its slowdown. Though it should be stressed that my results do not directly contradict those of Hulten, whose measure of technical change was confined to machinery and equipment within U.S. manufacturing, I will still attempt some reconciliation of my findings with those of Hulten at the end. The discrepancy in results suggests the possibility that the slowdown in investment in public infrastructure after 1973 may have played an important role in the post-1973 productivity slowdown.

Moreover, since this is only a note, I will not review the rather extensive literature on the productivity slowdown of the 1970's (see, for example, Edward F. Denison's [1979] and my [Wolff, 1985] review articles), except to list a number of factors that have been examined. The main candidates have included the slowdown in the rate of capital formation, changes in the composition of the labor force, the role of energy price shocks, declines in R&D spending (and/or the productivity of R&D), changes in the composition of output (mainly, the shift to services), and increased government regulation. Of these, the decline in investment appears to have played a major role, explaining about a fourth to a third of the slowdown in U.S. productivity growth after 1973.

In Section I, I present the basic data for the analysis. The basic regression results are presented in Section II. In Section III, I consider other possible factors that may have played a role in the productivity slowdown of the 1970's. Section IV provides a decomposition of labor productivity growth into its various sources, including a vintage effect, estimated by changes in the average age of capital. Section V analyzes the relative importance of each component in the falloff of productivity growth observed among OECD countries after

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1973. The last section presents some concluding comments, as well as a comparison with Hulten's results.

I. Basic Statistics and Methods

Table 1 shows the basic statistics for the entire economy from the period 1950–1989, based on data from Maddison (1991, 1993a, b).[1] Output is measured by GDP, the labor input by hours worked, and the capital input by gross nonresidential fixed plant and equipment in 1985 U.S. relative prices.[2] Capital stock estimates are standardized across countries by using the same service lives (a 39-year life for nonresidential structures and a 14-year life for machinery and equipment), as well as the same (U.S.) prices. Angus Maddison (1993b) graciously supplied me with unpublished figures on the age of the capital stock.

A word should be said about the estimation of the gross capital stock and average age. The capital-stock estimates are constructed using a perpetual-inventory method and assuming a fixed service life for assets. Actual retirements (or scrapping) of assets are not included in the estimation. Maddison argues that the pattern of retirements does not severely distort his estimate of gross capital stock. The average age at time t is then computed as a weighted sum of the investments at each time from $t - L + 1$ to t, where L is the service life of the asset and the weight is the age of the investment at time t, divided by the total capital stock at time t.

The average labor productivity growth of the six countries increased from 4.2 percent per year in the 1950–1960 period to 5.0 percent per year in 1960–1973, fell off sharply to 2.8 percent per year in 1973–1979 and then more moderately to 2.1 percent per year in 1979–1989. The slowdown in productivity growth between 1960–1973 and 1973–1979 occurred for all six countries; and that between 1973–1979 and 1979–1989 occurred for four of the six countries. Annual productivity growth in the United States in particular picked up between the two last periods, from 0.8 percent to 1.4 percent.

A somewhat different pattern is evident for total factor productivity (TFP) growth. TFP here is defined as

$$(1)\qquad \ln \mathrm{TFP}_t^h = \ln Y_t^h - \bar{\alpha} \ln L_t^h - (1 - \bar{\alpha}) \ln K_t^h$$

where Y^h is the total output of country h, L^h is labor input, K^h is capital input, and $\bar{\alpha}$ is the international average wage share. TFP growth, ρ, is then defined as

$$(2)\qquad \rho_t^h = \hat{Y}_t^h - \bar{\alpha}\hat{L}_t^h - (1 - \bar{\alpha})\hat{K}_t^h$$

where a "hat" (^) indicates the rate of growth. The Tornqvist approximation based on average period shares is employed. It also follows directly that

$$(3)\qquad \hat{\pi}_t^h = \rho_t^h + (1 - \bar{\alpha})\hat{k}_t^h$$

where $\pi \equiv Y/L$, the level of labor productivity, and $\hat{\pi}$ is the rate of labor productivity growth; and where $k \equiv K/L$, the ratio of the capital stock to labor, and $\hat{k}$ is the rate of growth of the capital–labor ratio. This will be useful later.

Annual TFP growth averaged 2.9 percent during 1950–1960 among the six countries, declined to 2.5 percent in 1960–1973, and then fell off precipitously to 0.9 percent in 1973–1979 and 0.8 percent in 1979–1989. Here too, TFP growth fell in all countries between 1960–1973 and 1973–1979, with Japan's falloff the most dramatic, from 4.0 percent to 0.1 percent per year, and in four of the six between 1973–1979 and 1979–1989. The two exceptions are Japan and the United States, both of whom experienced a rapid increase in TFP growth in the 1980's.

Also shown in Panel B is the ratio of the average TFP level of all countries except the United States to the TFP level of the United States. This is an index of the catch-up potential, extensively discussed in my 1991 paper. There was substantial catch-up on the U.S. level between 1950 and 1979, with the ratio rising from 0.61 to 0.83, but no change between 1979 and 1989.

[1] See the notes to Table 1 for sources.

[2] Figures on net capital stock are not available in Maddison (1993a).

TABLE 1—BASIC STATISTICS ON THE GROWTH RATES IN LABOR PRODUCTIVITY, TFP, AND THE CAPITAL–LABOR RATIO AND ON THE AVERAGE AGE OF CAPITAL STOCK, 1950–1989

Country	1950–1960	1960–1973	1973–1979	1979–1989	1989
A. *Average rate of labor productivity growth (percent per year):*					
France	4.46	5.15	3.73	2.66	
Germany	6.65	5.09	3.62	2.03	
Japan	5.54	8.70	3.14	3.21	
Netherlands	4.08	5.12	3.40	1.73	
United Kingdom	2.27	3.82	2.34	1.86	
United States	2.44	2.42	0.76	1.35	
Arithmetic average:	4.24	5.05	2.83	2.14	
B. *Average rate of TFP growth (percent per year):*					
France	2.93	2.72	1.11	0.95	
Germany	4.82	2.09	1.60	0.60	
Japan	4.92	4.01	0.11	1.21	
Netherlands	2.64	3.01	1.76	0.57	
United Kingdom	0.50	1.47	0.64	0.52	
United States	1.56	1.65	0.00	0.75	
Arithmetic average:	2.89	2.49	0.87	0.77	
Average TFP (excluding United States) to U.S. level, beginning of the period:	0.61	0.69	0.78	0.83	0.83
C. *Average rate of growth of gross capital to hours (percent per year):*					
France	3.80	6.03	6.49	4.24	
Germany	4.53	7.46	5.02	3.55	
Japan	1.53	11.65	7.54	4.97	
Netherlands	3.58	5.23	4.05	2.90	
United Kingdom	4.41	5.83	4.22	3.32	
United States	2.18	1.91	1.89	1.50	
Arithmetic average:	3.34	6.35	4.87	3.41	
D. *Average age of capital stock at the beginning of the period (in years):*					
France	17.3	14.8	9.8	9.7	11.6
Germany	16.3	12.4	10.4	11.0	13.3
Japan	12.1	11.1	7.7	8.6	10.4
Netherlands	18.0	15.1	11.3	11.5	13.9
United Kingdom	12.6	10.9	9.7	10.2	11.8
United States	16.1	14.6	12.4	12.8	13.6
Arithmetic average:	15.4	13.1	10.2	10.6	12.5
E. *Annualized change in average age of capital stock (in years):*					
France	−0.25	−0.39	−0.02	0.24	
Germany	−0.39	−0.16	0.10	0.29	
Japan	−0.10	−0.26	0.15	0.23	
Netherlands	−0.29	−0.29	0.02	0.31	
United Kingdom	−0.17	−0.10	0.08	0.21	
United States	−0.15	−0.17	0.07	0.10	
Arithmetic average:	−0.22	−0.23	0.07	0.23	

Notes: Output is measured by GDP in 1985 U.S. relative prices, labor by hours worked (employment times average hours per year), and capital by gross nonresidential fixed plant and equipment in 1985 U.S. relative prices. Factor shares used to compute TFP are based on the average ratio of employee compensation to GDP for the six countries over the 1950–1989 period.

Sources: For GDP, Maddison (1991 pp. 198–99, 216–19); employment, Maddison (1991 pp. 268–69), 1979 interpolated from Maddison (1982 p. 210); annual hours, Maddison (1991 pp. 270–71), 1979 interpolated from Maddison (1982 p. 211); capital stock, Maddison (1993a pp. 1–29); age of capital, Maddison (1993b), worksheets; factor shares computed from United Nations' *Yearbook of National Accounts Statistics,* selected years.

The growth in capital intensity (the ratio of gross capital to hours worked), averaged among the six countries, surged from 3.3 percent per year in the 1950's to 6.3 percent per year in 1960–1973, then declined to 4.9 percent per year in 1973–1979, and further to 3.4 percent per year during the 1980's. The slowdown occurred for all countries except France between 1960–1973 and 1973–1979 and for all countries between the latter period and the 1980's. Japan, in particular saw its annual percentage rate of capital–labor growth decline from 11.7 during 1960–1973 to 7.5 during 1973–1979, and then to 5.0 during 1979–1989.

The average age of the capital stock among the six countries (panels D and E of Table 1) declined from 15.4 years in 1950 to 13.1 years in 1960 and further to 10.2 years in 1973. This rejuvenation effect occurred for every country and was particularly notable in Germany during the 1950's and for France, Japan, and the Netherlands between 1960 and 1973. After 1973, the trend reversed, with the average age first increasing to 10.6 years in 1979 and then to 12.5 years in 1989. The aging effect happened in every country except France between 1973 and 1979 and in each of the countries between 1979 and 1989.

The data already point to a dramatic turnaround in the aging of the capital stock after 1973. In order to gauge the contribution of this phenomenon to the productivity slowdown, I now turn to a regression analysis to measure the vintage effect.

II. Regression Analysis of Labor Productivity Growth Trends

Of particular interest here is the so-called "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 negative correlation should be observed between the rate of productivity gain and the change in the average age of capital.

Following Hulten (1992), I can first distinguish between capital stock measured in natural units (constant prices), K, and capital stock measured in "efficiency units", K^*. To simplify, suppose that this year's capital investment is s-percent more productive than last year's, with the parameter s constant over time. To further simplify, suppose that investment occurs for a single year. Then, K^* measured in today's efficiency units is given by $K^* = K \cdot e^{-sA}$, where A is the age of the capital stock (investment). In the more general case, where investment occurs yearly and (gross) capital stock is accumulated investment over the service life, there is no simple relation between K^* and K, since it depends on the pattern of investment over time. However, one can very loosely approximate the relation as

$$(4) \qquad K^* = K \cdot e^{-s\bar{A}}$$

where $\bar{A}$ is the average age of the capital stock (see Richard R. Nelson, 1964). This equation simply states that the capital stock existing at time t is, on average, $s\bar{A}$-percent less efficient than the capital goods produced at time t.

Assuming a Cobb-Douglas aggregate production function, with capital measured in efficiency units, I then obtain

$$(5) \qquad \ln Y_t^h = \zeta_t^h + \bar{\alpha} \ln L_t^h + (1 - \bar{\alpha}) \ln K_t^h - (1 - \bar{\alpha}) s^h \cdot \bar{A}_t^h.$$

From (3) and (5) and with the added assumption that s is equal across countries, it follows that

$$(6) \qquad \hat{\pi}_t^h = \rho_t^h + (1 - \bar{\alpha}) \hat{k}_t^h - (1 - \bar{\alpha}) s \Lambda_t^h$$

where $\Lambda^h \equiv d\bar{A}^h/dt$, the rate of change in country h's capital-stock age (again, see Nelson, 1964).

The estimating form is

$$(7) \qquad \mathrm{LPGRT}_t^h = b_0 + b_1 \cdot \mathrm{RELTFP}_t^h + b_2 \cdot \mathrm{KLGRT}_t^h + b_3 \cdot \mathrm{AGEKCHG}_t^h + \varepsilon_t^h$$

where LPGRT_t^h is country h's annual rate of labor productivity growth over period t, RELTFP_t^h is country h's TFP relative to the United States at the start of each period t, KLGRT_t^h is country h's rate of capital–labor growth over period t, $\mathrm{AGEKCHG}_t^h$ is the

TABLE 2—REGRESSION OF LABOR PRODUCTIVITY GROWTH (LPGRT) ON RELATIVE TFP LEVEL, CAPITAL–LABOR GROWTH, AND THE CHANGE IN THE AVERAGE AGE OF CAPITAL

	Estimation technique		
Independent variables	OLS[a] (i)	OLS[a] (ii)	2SLS[b] (iii)
Constant	0.011**	0.008**	0.010
	(3.25)	(3.06)	(1.31)
RELTFP	−0.046**	−0.029*	−0.045**
	(5.78)	(2.67)	(2.89)
KLGRT	0.230*	0.404**	0.247
	(2.56)	(4.48)	(1.19)
AGEKCHG	−0.041**	−0.029**	−0.065*
	(6.18)	(4.79)	(2.42)
DELGDPGR		0.176*	
		(2.70)	
R^2:	0.90	0.94	0.82
Adjusted R^2:	0.89	0.93	0.79
Standard error:	0.006	0.005	0.008
Durbin-Watson:[c]	1.98	1.88	1.99
Sample size:[d]	24	24	24
d.f.:	20	19	20

Notes: Numbers in parentheses below each coefficient estimate are *t* statistics. LPGRT is the country's annual rate of labor productivity growth. RELTFP is the percentage difference between the country's TFP and U.S. TFP at the beginning of the period. KLGRT is the country's annual rate of capital–labor growth. ACEKCHG is the annualized change in the average age of the country's capital stock over the period. DELGDPGR is the change in the country's annual growth rate of GDP between the current period and the preceding period.

[a] The H. White (1980) procedure for a heteroscedasticity-consistent covariance matrix is used.

[b] Two-stage least squares. Instruments: DELGDPGR; DUMFRA, DUMGER, DUMJPN, DUMNET, and DUMUK (dummy variables for France, Germany, Japan, the Netherlands, and the United Kingdom, respectively).

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

[d] Observations are for France, Germany, Japan, the Netherlands, the United Kingdom, and the United States for four periods: 1950–1960, 1960–1973, 1973–1979, and 1979–1989.

* Significant at the 5-percent level.

** Significant at the 1-percent level.

(annual) change in the average age of country h's capital stock over period t, and ε is a stochastic error term. The error terms are assumed to be independently distributed but may not be identically distributed, and I used the White procedure for a heteroscedasticity-consistent covariance matrix in the estimation (also, see footnote 3 for additional tests on the error term). The sample consists of pooled cross-section time-series data, with observations on each of the six countries for 1950–1960, 1960–1973, 1973–1979, and 1979–1989.

Results for equation (7) are shown in column (i) of Table 2. The constant term, which is, in a sense, a measure of the "normal" rate of TFP growth, is estimated at 1.1 percentage points per year. The catch-up effect (RELTFP, the initial relative TFP level) is significant at the 1-percent level, and its coefficient has the expected negative sign. The coefficient estimate is −0.046, indicating that a 50-percent difference between a country's initial TFP and that of the United States is associated with growth in labor productivity of about 2.3 percentage points per year (half of −0.046).

Capital–labor growth is significant at the 5-percent level and has the expected positive sign. A 1-percentage-point increase in capital–labor growth is associated with a 0.23-percentage-point increase in labor productivity growth. The change in the average age of the capital stock has the expected negative sign and is significant at the 1-percent level. The effect is surprisingly large: a one-year reduction in the average age over the year is associated with about a 4.1-percentage-point increase in annual labor productivity growth. The goodness of fit is remarkably high for a simple regression of this sort, with an adjusted R^2 of 0.89.

Alternative specifications were also used. First, I included dummy variables for each country (except the United States) to control for country-specific effects, such as the degree of trade openness, culture, and government policy. The joint hypothesis that the coefficients of the country dummy variables equal zero was not rejected ($F_{[5,\,15]} = 0.18$, compared to a critical value of $F_{0.05}$ of 4.6). Second, period dummy variables (except for 1950–1960) were included to allow TFP growth to vary by period—in response, for example, to unevenness in the flow of new technology or inventions. The joint hypothesis that the coefficients of the period dummy variables equal zero was not rejected ($F_{[3,\,17]} = 1.48$, compared to a critical value of $F_{0.05}$ of 5.2). One noteworthy finding is that the dummy variable for the 1973–1979 period is not significantly different from zero.

Third, the assumption that the production function given by equation (5) is the same in each country may be unduly restrictive. I relaxed this assumption in two ways. First, I allowed the coefficient of KLGRT to vary across countries by introducing interactive terms between KLGRT and each of the five country dummy variables. The joint hypothesis that the coefficients of the country interactive variables equal zero was not rejected ($F_{[5,\,15]} = 0.11$, compared to a critical value of $F_{0.05}$ of 4.6). Moreover, none of the interaction terms was individually statistically significant. Second, I allowed the coefficient of AGEKCHG to vary across countries by introducing interactive terms between AGEKCHG and each of the five country dummy variables (i.e., allowing different vintage effects across countries). The joint hypothesis that the coefficients of the country interactive variables equal zero was not rejected ($F_{[5,\,15]} = 4.43$, compared to a critical value of $F_{0.05}$ of 4.6). Moreover, here again, none of the interaction terms was individually statistically significant. Similar tests in which the coefficients of KLGRT and AGEKCHG were interacted with country dummy variables (allowing the production function in each country to vary over time) proved statistically insignificant.[3]

How do these figures compare to Hulten's estimate of the rate of embodied technical efficiency for the United States over the 1949–1983 period, of 3.4 percent per year (p. 977)? From (6) and (7), my estimate of s, the rate of embodied technical change is given by $-\hat{b}_3/\hat{b}_2$, which is 18.9 percent per year. This is substantially higher than Hulten's figure. However, this estimate may be biased upward by the omission of a potentially crucial variable, as I will discuss below.

III. Other Possible Explanations

There are several other factors that might account for the pattern of productivity growth observed among OECD countries, particularly the slowdown after 1973. I will discuss three of these here.

A. *The Change in Output Growth*

There are three potential arguments in support of an effect due to the change in output growth. First, as suggested by Robert J. Gordon (1979), firms may hoard labor in the face of a slowdown in output growth. This effect, in turn, may be due to a firm's interest in retaining workers in whom it has invested training time, a firm's desire to avoid the high

[3] Other tests were performed on the error term. First, the observations were ordered by time within each country in order to test for autocorrelation. The Durbin-Watson statistic, shown in Table 2, falls within the critical range at the 5-percent level. Second, Ramsey RESET functional-form tests were performed for the square and cube of the predicted value of the dependent variable, with none significant at the 5-percent level (the $F_{[2,\,19]}$ statistic is 3.87, compared to a critical value of 5.93 at the 5-percent level).

costs of rehiring in the subsequent expansion, the role of professional and managerial labor as "overhead" employment, rigid worker regulations (particularly in Europe) which make the costs of layoff high, and the like (see John A. Tatom, 1979). Conversely, during the early stages of expansion, firms may be reluctant to hire new workers because of the high costs of hiring and training and the like. Though this effect is usually cited to explain the slowdown in productivity growth at the beginning of a recession and its upturn during the start of cyclical expansion, it may also hold for medium-term effects.

The second argument invokes a positive feedback effect between output growth and productivity growth of the sort known as the P. J. Verdoorn (1949) or Nicholas Kaldor (1967) effect. The general form of the argument is that increased output associated with an expanding market will lead to increased economies of scale, greater specialization of production, and new investment embodying the latest technology, which in turn allow price to decline and result in a further expansion of the market.

Both arguments suggest a positive relation between the change in output growth (DELGDPGR) and the rate of labor productivity advance. Column (ii) of Table 2 shows the results of adding DELGDPGR to equation (7). The coefficient of DELGDPGR is significant at the 5-percent level. Its value of 0.18 indicates that a 1-percentage-point decline (increase) in the annual rate of output growth is associated with a 0.18-percentage-point fall (gain) in annual labor productivity growth.

The coefficient of RELTFP falls slightly, and its significance level falls from the 1- to the 5-percent level. On the other hand, the coefficient of KLGRT increases from 0.23 to 0.40, and its significance level rises to the 1-percent level. The coefficient of AGEKCHG remains significant at the 1-percent level, though its value changes from −0.041 to −0.029. The estimated value of s, the rate of embodied technical change, is now 7.2 percent per year, much closer to Hulten's original estimate.

The overall fit of the equation improves also (the adjusted R^2 increases from 0.89 to 0.93, and the standard error falls from 0.006 to 0.005). The Durbin-Watson statistic again falls within the critical range at the 5-percent level.

A third argument was suggested to me by Charles Hulten. He pointed out that the age of capital may not be exogenous. In particular, in an accelerator model, investment can be viewed as a function of the change in the rate of output growth. If output growth slows (e.g., due to an exogenous shock or a slowdown in the rate of disembodied technical change), the reduction in the investment rate will lead to an increase in the average age of the capital stock. If output growth accelerates (e.g., due to rapid catch-up for technologically backward countries), investment rises and the average age declines. In such a model, a negative coefficient on AGEKCHG may be obtained even when technical change is entirely disembodied.

I use two-stage least squares (2SLS) to test this line of argument, since if AGEKCHG were endogenous, then using it as a right-hand-side variable in OLS estimation would result in a biased and inconsistent estimator of the coefficient of AGEKCHG. I first specified a simple accelerator model for the investment rate, with the following results:

$$\begin{aligned}\text{INVRATE} = {} & \underset{[5.86]}{0.067} - \underset{[2.61]}{0.397}\,(\text{DELGDPGR}) \\ & + \underset{[1.25]}{0.020}\,(\text{DUMFRA}) + \underset{[2.85]}{0.046}\,(\text{DUMGER}) \\ & + \underset{[5.21]}{0.085}\,(\text{DUMJPN}) + \underset{[1.37]}{0.022}\,(\text{DUMNET}) \\ & + \underset{[0.05]}{0.001}\,(\text{DUMUK}).\end{aligned}$$

The summary statistics are: $N = 24$; $R^2 = 0.71$; $\bar{R}^2 = 0.61$; standard error = 0.023; Durbin-Watson statistic = 2.25. INVRATE_t^h is country h's average investment rate (the ratio of investment in 1985 U.S. dollars to GDP in 1985 U.S. dollars) over period t; DUMFRA, DUMGER, DUMJPN, DUMNET, and DUMUK are dummy variables for France, Germany, Japan, the Netherlands, and the United Kingdom, respectively; and t ratios are shown in brackets underneath the coefficients. Because of a paucity of suitable variables, I was forced to use dummy variables for country characteristics. Despite this, the fit is reasonably good, with an adjusted R^2 of 0.61. The coefficient of DELGDPGR has the expected negative sign and is significant at the 2-percent level.[4]

The second step is to run two-stage least squares on equation (7), with DELGDPGR, DUMFRA, DUMGER, DUMJPN, DUMNET, and DUMUK as instruments. The results, shown in column (iii) of Table 2, are quite close to the OLS estimates of column (i). The coefficient of RELTFP is unchanged, as is its significance level; that of KLGRT is slightly greater, though it is no longer significant; the coefficient of AGEKCHG is now magnified, though its significance level falls to the 5-percent level; and the goodness of fit is slightly poorer. However, overall, the results contradict the hypothesis that technical change is disembodied—in particular, the coefficient of AGEKCHG remains negative and statistically significant.

B. *R&D Spending*

A decline in R&D intensity, defined as the ratio of R&D expenditures to GDP, may have been responsible for the post-1973 productivity slowdown. Here, cross-country data are somewhat limited. Maddison (1987 p. 695) provides figures on the six countries for 1960, 1973, and 1983. I have augmented these data with figures for 1979 and 1987 drawn from the UNESCO *Statistical Yearbook, 1990*. On the surface, at least, this variable does not look like a promising candidate, since average R&D intensity among these six countries increased from 1.8 percent in 1960 to 2.0 percent in 1973, 2.1 percent in 1979, and 2.5 percent in 1987. In other words, even though the rate of labor productivity growth slowed down after 1973, R&D intensity continued to increase.

Regression analysis confirms this suspicion. I added RDGDP (the ratio of R&D expenditures to GDP, averaged over each period) to equation (7).[5] Because of data limitations, the sample is restricted to three periods: 1960–1973, 1973–1979, and 1979–1989. The coefficient estimate for RDGDP is 0.047 but it is not significant (the t ratio is 0.10). The results for the other variables are almost the same as in column (i) of Table 2.[6]

C. *The Growth in Mean Years of Schooling*

A reduction in the rate of growth of schooling, interpreted as an index of labor skill, may have caused productivity growth to slow. However, here again, the surface evidence does not appear to support this presumption. Based on data from Maddison (1987, 1991), mean years of formal education of the population aged 15–64, averaged over the six countries in the sample, grew from 9.0 years in 1960 to 9.9 years in 1973, 10.4 years in 1979, and 11.3 years in 1989. The annual rate of growth of mean schooling was almost identical in the 1960–1973 and 1973–1979 periods (0.75 percent) and even higher in the 1979–1989 period (1.1 percent).

To test its effect, I added EDUCGRTH (the annual growth rate of mean formal schooling) to equation (7).[7] The coefficient estimate of EDUCGRTH is 0.60, and it is significant at the 10-percent level (the t ratio is 1.98). The coefficient of the constant terms drops from 0.011 to 0.007, but the coefficient estimates of the other variables are largely unaffected. In particular, the vintage effect is actually somewhat stronger (the coefficient estimate is now −0.045, compared to −0.041).[8]

IV. Decomposition of Productivity Growth

A decomposition, based on the regression results of Table 2, is shown in Table 3. I have selected the results of the second regression in Table 2 because it provides the best fit (the highest adjusted R^2 and the lowest standard error) of all the forms used.

[4] The Durbin-Watson statistic falls within the indeterminate range in this case.

[5] This specification for R&D intensity is standard (see e.g., Zvi Griliches, 1979).

[6] When DELGDPGR is also included in the equation, the coefficient of RDGDP actually turns negative, though it remains statistically insignificant.

[7] This specification is also standard (see e.g., N. Gregory Mankiw et al., 1992).

[8] Results are similar when DELGDPGR is also included in the equation.

TABLE 3—CONTRIBUTION OF EACH COMPONENT TO AVERAGE LABOR PRODUCTIVITY GROWTH BY PERIOD

	1950–1960	1960–1973	1973–1979	1979–1989
A. *Average values of explanatory variables:*				
RELTFP	−0.32	−0.30	−0.27	−0.20
KLGRT (percentage points)	3.34	6.35	4.87	3.41
AGEKCHG	−0.22	−0.23	0.07	0.23
DELGDPGR (percentage points)	3.11	0.80	−2.50	−0.75
B. *Percentage-point contribution of each variable to average labor productivity growth:*[a]				
Constant	0.81	0.81	0.81	0.81
RELTFP	0.93	0.87	0.77	0.59
KLGRT	1.35	2.56	1.97	1.38
AGEKCHG	0.65	0.65	−0.20	−0.67
DELGDPGR	0.55	0.14	−0.44	−0.13
Unexplained	−0.05	0.01	−0.08	0.16
LPGRT	4.24	5.05	2.83	2.14

Note: See notes to Table 2 for variable definitions.

[a] Defined as coefficient value multiplied by the average value of the variable by period. Coefficients are from regression (ii) in Table 2.

Over the 1950–1960 period, of the 3.1 percent per year average growth in labor productivity, 0.81 percentage points can be attributed to general technological advance (the constant term), 0.93 percentage points to the catch-up effect (RELTFP), 1.35 percentage points to the growth in the capital–labor ratio (KLGRT), 0.65 percentage points to the vintage effect (the decline in the average age of the capital stock, AGEKCHG), and 0.55 percentage points to the acceleration in output growth (DELGDPGR), with −0.05 points unexplained.

The catch-up effect was strongest over the 1950–1960 period, when the U.S. lead had become most formidable. However, the effect atrophied over time, from a contribution of 0.93 points during the 1950's to 0.59 points during the 1980's, as the TFP gap narrowed to 17 percent of the U.S. level. The contribution of capital–labor growth almost doubled, from 1.4 percentage points during the 1950's to 2.6 percentage points during the years 1960–1973, reflecting the dramatic surge in capital investment. Its effect then diminished, to 2.0 percentage points in the 1973–1979 period and then to 1.4 points in the 1979–1989 period.

The vintage effect made a very strong contribution to labor productivity growth during the years 1950–1960 and 1960–1973 of 0.65 percentage points, reflecting the sharp decline in the average age of capital. However, the 1973–1979 and 1979–1989 periods saw a sharp turnaround, as capital aged in both periods, and the vintage effect created a drag on productivity growth. Its contribution was −0.20 percentage points in the former and −0.67 percentage points in the latter.

The rapid acceleration in output growth (DELGDPGR) during the 1950's contributed 0.55 percentage points to labor productivity growth during those years. However, the effect lessened during the 1960–1973 period, to 0.14 points, and then turned negative in the 1973–1979 period (−0.44 points) and the 1979–1989 period (−0.13 points). The unexplained portion was very small in all four periods (a maximum of 0.16 percentage points).

V. Sources of the Productivity Slowdown

It is now possible to analyze the contributions of the various factors to the productivity slowdown after 1973. This is accomplished by first-differencing the contributions of each component between the 1973–1989 and the 1960–1973 periods and dividing the difference by the change in labor productivity growth between those periods. Results are shown in Table 4.

TABLE 4—PERCENTAGE OF THE CHANGE IN ANNUAL LABOR PRODUCTIVITY GROWTH BETWEEN 1960–1973 AND 1973–1989 EXPLAINED BY EACH COMPONENT

Country	Catch-up effect (RELTFP)	Capital–labor growth (KLGRT)	Vintage effect (AGEKCHG)	Acceleration in output growth (DELGDPGR)	Unexplained (residual)	Sum	Actual percentage change in LPGRT
France	13.0	18.3	69.3	32.0	−32.6	100.0	−2.08
Germany	−3.9	54.9	40.0	−8.1	17.1	100.0	−2.47
Japan	5.4	41.8	22.6	19.3	10.8	100.0	−5.52
Netherlands	10.3	27.9	47.1	18.9	−4.2	100.0	−2.76
United Kingdom	−10.5	49.1	37.8	14.9	8.6	100.0	−1.78
United States	0.0	8.1	55.2	26.2	10.5	100.0	−1.29
Average:	3.6	36.4	40.0	25.1	−5.2	100.0	−2.65

Notes: The percentages reported above are computed from results of Table 3. The average values are based on the change in the mean value of each variable, averaged over the six countries.

Annual labor productivity growth, averaged across the six countries, declined by 2.7 percentage points between these two periods. The vintage effect was the most important source, explaining, on average, 40 percent of the slowdown, as the capital stock declined in age during the first period and aged over the second. The slowdown in capital–labor growth accounted for another 36 percent of the productivity slowdown. The deceleration in GDP growth explained 25 percent, while the diminution of the catch-up effect accounted for only 3.6 percent of the productivity slowdown. The unexplained portion was 5 percent.[9]

The effects vary across countries. For the United States, the vintage effect accounted for 55 percent of its productivity slowdown, with slower capital–labor growth accounting for 8 percent and the decline in GDP growth for 26 percent, leaving 11 percent unaccounted for.

[9] Not surprisingly, the vintage effect appears much stronger when the change in output growth (DELGDPGR) is not included in the regression, accounting for, on average, 57 percent of the labor productivity slowdown between these two periods. On the other hand, including the growth in average schooling (EDUCGRTH) in the regression has virtually no effect on the estimated contribution of the vintage effect (or the contributions of the other components) to the productivity slowdown, since the annual growth in schooling changed very little between the 1960–1973 and 1973–1989 periods. Including EDUCGRTH does reduce the importance of general technological advance (the constant term) to annual productivity growth in each period.

For France, the turnaround in the vintage effect was the predominant factor (69 percent) in its productivity growth slowdown, as was the case for the Netherlands (47 percent). For Germany, Japan, and the United Kingdom, the slowdown in capital formation was the major cause of their productivity growth declines, with the vintage effect accounting for 40 percent, 23 percent, and 38 percent, respectively.

Moses Abramovitz (1994) also provides estimates of the vintage effect. His results are based on a growth-accounting procedure. Using (an older vintage of) data from Angus Maddison, he estimates that, on average, about 16 percent of the productivity slowdown between 1950–1973 and 1973–1984 can be ascribed to the change in the average age of capital. Interestingly, at the outset of the analysis, he imposes the condition that only half of technical change is embodied in capital, an assumption which may account for his lower estimate of the contribution of the vintage effect to the productivity slowdown.

VI. Concluding Remarks

It is, perhaps, most revealing to look at the productivity slowdown from a long-term perspective. Moreover, as I argued previously (Wolff, 1991), it is fruitful to consider the 1950–1973 period as the aberrant one and the post-1973 period as a return to normality, rather than the reverse.

On the basis of historical data of the last 100 years for (today's) OECD countries, the normal rate of technical advance on the frontier (TFP growth) has been on the order of 0.5–1.0 percentage points per year. (This result also falls out of the regression analysis.) Capital–labor growth has typically run around 2 percent per year, yielding a normal annual labor productivity growth of 2 percent or so (see my 1991 paper for details).

These usual relations were interrupted by two major crises: the Depression of the 1930's and World War II and its subsequent recovery years. During the Depression, the United States actually lost ground in absolute terms in terms of TFP and experienced very low labor productivity growth. Not all countries were so adversely affected. Japan's productivity, for example, mushroomed over the period from 1929 to 1938.

The United States made up for lost ground over the years 1938–1950, when it enjoyed its highest labor productivity and TFP growth ever. On the other hand, continental Europe and Japan experienced very low or even negative growth in productivity. As a result, by 1950, the TFP gap between the United States and other countries was at its highest level ever.

Japan and continental Europe made up their lost ground during the 1950–1973 period. The high labor productivity growth of the 1950's and 1960's was driven by the catch-up effect, which added about 1 percentage point per year. This was coupled with a very high rate of capital–labor growth, during the 1950's, adding 1 percentage point, and particularly during the 1960's, adding 2–3 percentage points per year. (The two events are probably not unrelated.) The catch-up effect had to abate over time, and it did, as the TFP gap closed between the United States and the other countries. Capital–labor growth also fell off after 1973, which further retarded labor productivity growth.

Another favorable factor, at least during the 1950's, was the acceleration in output growth. As suggested above, a change in output growth might affect measured labor productivity if internal labor markets are rigid or if there are positive feedback effects between expanding markets, specialization, economies of scale, and embodied technical change. This factor added $^1/_2$ percentage point to labor productivity growth during the 1950's though very little during the 1960–1973 period. The retardation in output growth back to more normal levels, which was bound to occur, reduced annual labor productivity growth by about $^1/_2$ percentage point during the 1973–1979 period, though it had little effect over the 1979–1989 period.

What also made the 1950–1973 period so unusual was the tremendous decline in the average age of the capital stock. The vintage effect added another $^2/_3$ percentage point per year to labor productivity growth. Normally, if capital growth is relatively steady over time, the age of the capital stock is also constant, and there is no vintage effect. A sizable *acceleration* in capital growth is necessary to obtain any significant reduction in the average age of the capital stock and thus a significant vintage effect. The years 1950–1973 represent the only period when this occurred. After 1973, the *deceleration* in capital growth caused the reduction in capital age to halt, and indeed, over the 1973–1989 period, there was an aging of the capital stock.

In this sense, the vintage effect explains about two-fifths, on average, of the post-1973 labor productivity slowdown among OECD countries and, for the United States in particular, about one-half. Actual estimates, as is apparent, are very sensitive to the period covered, the periodization, data sources and concepts, and the sample of countries.

However, as suggested, if the 1950–1973 period is the historical aberration, then its exceptionally high labor productivity growth is due to a combination of four favorable conditions: a large catch-up effect, very strong capital–labor growth, a sizable vintage effect, and a rapid acceleration in output growth (at least during the 1950's).

This is not to say that the post-1973 period (particularly, 1973–1979) was perfectly normal. Indeed, one aberrant feature of this period was the aging of the capital stock, which created a drag on productivity growth. This effect, however, will eventually wear off as the growth in the capital stock stabilizes (or, perhaps, even increases). As a result, one may expect that labor productivity growth rates should soon pick up among OECD countries.

Why was the importance of the vintage effect in accounting for the productivity slowdown not seen before? The main reason is that in the long-term analysis of productivity growth, the change in the age of the capital stock is quite small, and the vintage effect washes out. Over the 1950–1989 period, for example, the average age of the capital stock declined by 2.9 years, contributing only 0.2 percentage points to annual average labor productivity growth over this period. Thus, most investigators discounted the vintage effect as an explanation of the slowdown.

The mystery was to find a variable whose value could change sharply over a short period of time in order to explain the *precipitousness* of the productivity slowdown. Most first derivatives, like the change in the capital stock (the investment rate) do not have this property. However, second derivatives, like the change in the change in the capital stock, can fluctuate abruptly over time. Thus, the change in the average age of the capital stock (a third derivative!) can take on large values. This type of effect is similar to the type one obtains from an accelerator model of investment described above.

It is left to "reconcile" my findings with Hulten's estimates, which give such a low explanatory power to the embodiment effect in accounting for the productivity slowdown in U.S. manufacturing after 1973. At the outset, it should be noted that "reconcile" is really too strong a term, since there is no direct inconsistency between my results (for the total economy) and Hulten's (for manufacturing only). Moreover, Hulten's estimates are based on figures for machinery and equipment only, whereas mine are derived from the total capital stock (structures, machinery, and equipment). In addition, Hulten's methodology and data sources are very different from mine and are based only on U.S. data. He estimates an embodiment effect directly, from real quality-adjusted (hedonic) price movements of machinery and equipment components, rather than from a vintage effect. Hulten's periodization is also somewhat different than mine. Finally, Hulten's figures on TFP growth are based on gross output and three inputs: labor, capital, and intermediate inputs.[10]

Let me first address the difference in our estimates of the rate of embodied technical efficiency, s, for the United States: mine of 7.18 percent per year estimated from regression (ii) of Table 2 and Hulten's of 3.44 percent per year (though for manufacturing only). It is well known that measures of TFP growth which are derived from gross output and include intermediate inputs in addition to labor and capital are much lower than those based on value-added and labor and capital only. The reason is that intermediate inputs, which typically comprise about half of gross output, tend to remain fairly constant as a share of gross output, so that almost all the gains in TFP originate from reductions in labor and capital inputs. In Wolff (1994) I calculated from U.S. input–output data covering the 1967–1982 period in the United States that the annual growth of TFP derived from gross output data averaged 39 percent of the corresponding TFP growth rate based on value-added data. A similar adjustment (of 39 percent) to the TFP figures in the regressions reported above would have yielded an estimate of s of 2.79 percent per year.

The two estimates of s are now in the same ballpark, though mine is somewhat lower. There are two potential reasons. First, capital in manufacturing is apt to be, on average, subject to more technical improvements over time than capital in other sectors. Second, capital other than machinery and equipment is likely to be subject to fewer quality improvements over time.

If I extend the estimation of the embodiment effect from machinery and equipment only to total capital, then two changes occur in the estimation of the contribution of the embodiment effect to technical change. First, the share of capital in total output in the United States over the 1949–1983 period increases from Hulten's figure of 13 percent (machinery and equip-

[10] Another technical difference is that Hulten adjusts his output figure to incorporate the effects of embodied technical change on the real output of investment goods. This is important for an analysis of the manufacturing sector, since it produces most of the investment goods. However, my calculations indicate that his adjustment would make a minor difference in my results on the sources of the post-1973 productivity slowdown for the *entire economy*.

ment only) to 37 percent (the average share of nonlabor income in gross national income, defined as the sum of national income and capital consumption).[11] Second, the change in the average age of capital before and after 1973 is greater. On the basis of Maddison's (1993b) data, the average annual change in the average age of machinery and equipment in the United States was 0.010 between 1949 and 1973 (Hulten's period) and 0.057 between 1974 and 1983. In contrast, the average annual change in the average age of total capital was −0.165 from 1949 to 1973 and 0.090 from 1974 to 1983.

Using Hulten's estimate of the rate of embodied technical efficiency for the United States over the 1949–1984 period of 3.44 percent per year and my equation (6) to calculate the vintage effect, I find that the vintage effect would have contributed 0.21 ($-3.44 \times -0.165 \times 0.37$) percentage points to overall technical change in the 1949–1973 period and −0.11 ($-3.44 \times 0.090 \times 0.37$) percentage points in the 1974–1983 period. Thus, of Hulten's value of 1.37 percentage point per year for the change in the residual growth of quality-adjusted output between these two periods, 24 percent (0.32/1.37) could be attributed to the vintage effect. Using my estimates of TFP growth for the entire economy and adjusting from a value-added basis to a gross output basis, the figure jumps to just about 50 percent, which is what I estimated above.

It follows from the discrepancy between my results and those of Hulten that decreases in the average age of components of the capital stock *other than* machinery and equipment made an important contribution to increases in labor productivity before 1973, while increases in the average age of this component reduced labor productivity after 1973. The two leading candidates are structures and public infrastructure. While buildings are unlikely to be subject to sharp quality improvements over time,[12] research by David A. Aschauer (1989a, b) has shown that (i) the return to public investment is substantially higher than the return to private investment and (ii) the growth in public infrastructure has declined since the early 1970's. Maddison's figures (on which the estimates of this paper are based) include government capital stock. Therefore, the present research, taken together with that of Hulten and Aschauer, points to the intriguing hypothesis that changes in public investment may have been an important source of recent sharp changes in the rate of productivity growth. Since this issue has particular policy relevance, future research might profitably benefit from the construction of comparable standardized estimates of public capital to test this hypothesis.

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[11] I use gross national income rather than (net) national income in order to maintain consistency with the use of gross stocks of capital.

[12] This is not to say that structures are completely inert, since improvements in power sources, energy usage, electrical and computer systems, and telecommunications, as well as the introduction of flexible work systems to the shop floor and the like, usually entail the construction of a new plant or the extensive remodeling of existing buildings.

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