Volume Title: International Economic Transactions: Issues in Measurement and Empirical Research

Volume Author/Editor: Peter Hooper and J. David Richardson, editors

Volume Publisher: University of Chicago Press

Volume ISBN: 0-226-35135-1

Volume URL: http://www.nber.org/books/hoop91-1

Conference Date: November 3-4, 1989

Publication Date: January 1991

Chapter Title: Macroeconomic Convergence: International Transmission of Growth and Technical Progress

Chapter Author: John F. Helliwell, Alan Chung

Chapter URL: http://www.nber.org/chapters/c8436

Chapter pages in book: (p. 388 - 436)

11 Macroeconomic Convergence

International Transmission of Growth and Technical Progress

John F. Helliwell and Alan Chung

11.1 Introduction

Most studies of international transactions treat countries as essentially unaffected by trade, with their basic production technologies remaining unchanged by international contacts. However, there is a growing body of evidence that there is some international convergence of technical progress, especially among the industrial countries that have dominated world production and trade over the past thirty years. This paper attempts to evaluate the evidence, based on data for nineteen industrial countries over the period from 1960 to 1985. One important goal of the paper is to see whether the extent of convergence is altered by the degree to which countries have become more open to international trade. We will also assess the extent to which the cross-country evidence supports the hypothesis that there are increasing returns at the national level in the use of knowledge as a factor of production.[1]

A second aim, based on the conference focus, is to see to what extent the evidence of convergence depends on some key questions of measurement, including the exchange rates used to compare real output in different coun-

---

John F. Helliwell is professor of economics at the University of British Columbia and a research associate of the National Bureau of Economic Research. Alan Chung is at the Department of Economics, University of British Columbia.

Many helpful comments on earlier drafts were provided by Martin Baily, Barry Eichengreen, Peter Hooper, Irving Kravis, Robert Lawrence, Edward Leamer, Robert Lipsey, Catherine Mann, Samuel Pizer, David Richardson, and Guy Stevens. The authors are grateful for the continuing financial support of the Social Sciences and Humanities Research Council of Canada.

[1] If this knowledge is domestically produced and owned, this implies that levels of per capita real income should diverge rather than converge as time passes, and that growth rates should "be increasing not only as a function of calendar time but also as a function of the level of development" (Romer 1986, p. 1012). If the external benefits of technical progress are available freely to all those in the national economy, as in the models developed by Romer and by Grossman and Helpman (1989b), then the appropriate scale variable is the level of aggregate total output rather than per capita output.

tries, the measurement and selection of the capital stocks to use in aggregate production functions, and alternative ways of representing embodied or disembodied technical progress.

This evidence on the international transmission of longer-term trends in technical progress will be based on a model in which the level of output is jointly determined by the underlying production structure and unexpected changes in demand and cost conditions. In a subsequent section dealing with shorter-term fluctuations of aggregate output, this framework will be compared with the production sector specification frequently used in real business cycle models of output determination, in which the level of output is based on a continuously binding production structure plus an autocorrelated series of technology shocks.

The three objectives listed above are each the focus of a separate section of the paper; following is a concluding section summarizing our results and two appendixes, the first describing the sources and construction of our alternative data series and the second describing our econometric specifications and test results in more detail.

11.2 What is the Evidence for International Convergence?

An important element in the international comparison of the levels and growth of per capita income and factor productivity has been the idea that growth rates, and perhaps levels, of productivity and real income, should converge over time.[2] To test this notion, it is first necessary to have internationally comparable measures of real income. In turn, data are required on purchasing power parities (PPP), in order to make income levels internationally comparable.[3] To extend the analysis to factor productivity, it is also necessary to have comparable data on real output, as well as on the inputs of capital and labor, if not also of natural resources. In this section we will make use of what we think to be the most comparable data for these purposes, and in the following section we will consider how the results might differ if alternative assumptions or data sources were used for some of the key variables.

The intuition behind the convergence hypothesis is that the ideas and techniques underlying economic progress are transportable across national bound-

---

[2] Convergence has also been seen as one of the factors explaining some of the post-1973 slowdown of productivity growth in countries outside the United States, e.g., by Nordhaus (1982), Lindbeck (1983), Maddison (1987), Helliwell, Sturm, and Salou (1985), and Englander and Mittelstadt (1988). There is also international evidence of convergence at the industry level, as shown by Dollar and Wolff (1988).

[3] This is true unless market exchange rates alter so as to maintain PPP in level form. Even then, estimates of PPP exchange rates would be required to assure that the exchange rates had indeed moved so as to maintain absolute PPP. In any event, Heston and Summers (1988) show that there are large and systematic departures of market exchange rates from their PPP values, such that market exchange rates consistently fall below PPP values for the poorer countries. Thus, international real income comparisons based on market exchange rates overstate the real income differentials between the rich and poor countries, as emphasized by Kravis and Lipsey (1984).

aries with increasing ease, so that nations starting out with lower levels of per capita income should be able to benefit not only from improvements in international best-practice technology, but also from the ability to close the gap between their previous methods and those used in the more advanced economies. Many qualifications are necessary:

1. The technologies of the richer countries may be relevant for relative factor prices and education levels existing in the richer countries, but not directly applicable to conditions existing in the poorer countries.[4]
2. The political and social systems of the poorer countries may not be ready or willing to accept the degree of international interdependence implied by the relatively unrestricted movement of technologies and production.[5]
3. The technologies themselves may be privately owned. Their importation might lead to higher levels of GDP per capita in the poorer country, but not of GNP per capita, if the rents attributable to the technologies accrue to foreign-owned firms.
4. Countries that may at one time have been in the vanguard of economic progress may for any number of reasons lose the desire or ability to design or keep up with productivity improvements.[6]

All of these qualifications suggest that the evidence for convergence is likely to be stronger among countries with reasonably comparable initial levels of income, which are open enough to international trade and investment that the necessary conditions for convergence are likely to be met. Evidence covering a hundred years of development of the currently rich countries shows considerable evidence of convergence (Maddison 1982, Baumol 1986). However, De Long (1988) emphasizes that there may be a sample-selection problem here and shows that the evidence for convergence is much weaker, and may even disappear, if the sample is increased to include some countries that were seen a hundred years ago to be promising candidates for continued economic growth.[7] Much larger samples of countries (which include many of the poorest countries) show weaker evidence of convergence over the past thirty

---

[4] Rauch (1989) tests this idea by defining a "convergence club" of twenty countries that had illiteracy rates below 5 percent in 1960 and finds much stronger evidence of convergence than for much larger groups of countries. His proposed convergence club, based on 1960 literacy levels, differs from our sample of nineteen industrial countries in excluding Italy and Spain and adding three very small countries (Barbados, Iceland, and Luxembourg).

[5] Following Ohkawa and Rosovsky (1973), Abramovitz (1986) refers to the factors influencing the ability of a society to benefit from catch-up or convergence as "social capability," which he roughly approximates by a measure of average years of schooling combined with consideration of the adaptability of the nation's political, commercial, industrial, and financial institutions. Psacharopoulos (1984) reviews various studies of the contribution of education to growth, most of which assume that the contribution is continuous and separable, and not part of the definition of the necessary conditions for a "take off" (Rostow 1978) for sustained catch-up growth.

[6] These possibilities are emphasized by Abramovitz (1986) and De Long (1988).

[7] See De Long (1988) and Baumol and Wolff (1988).

years.[8] For these much larger samples of countries, the necessary conditions for convergence are less likely to be met, and the data are not available to assess the extent to which productivity and income levels are simultaneously converging. To allow a clear focus on productivity comparisons, we restrict ourselves in this paper to a consideration of the growth experience of nineteen industrial countries for which reasonably comparable annual data are available for the period from 1960 through 1985, for PPP exchange rates, capital stocks, real output, and labor inputs. Even here, a number of difficult and sometimes arbitrary decisions have to be made to achieve completeness and comparability of data. We will return to these issues in the next section, after presenting our initial results on convergence among the nineteen industrial countries.

The primary sources of our data are the national accounts published by the OECD for the industrial countries, converted to common currency using PPP exchange rates for GDP.[9] The capital stock and employment data are also mainly from OECD sources, as described in appendix A. The primary measure of productivity used for the convergence tests is, for each country, a time series of real GDP attributable to each worker, derived by inverting a constant elasticity of substitution (CES) production function with common parameters, using a country-specific average real return to aggregate capital. International differences in average returns to capital thus pick up average returns to natural resources, education, market power, and other factors to the extent that they are not captured by differences in real wages.

The maintained hypothesis, in our base case, is that technical progress is labor-augmenting and follows a growth path that asymptotically approaches a path parallel to that of the United States. The United States is taken to be the base for the initial tests of the convergence hypothesis, since the PPP data show it to have the highest level and the smallest average rate of growth of capital-adjusted real output per employee over the sample period. We will consider later the implications that increasing internationalization might have for the definition of the source and rate of growth of technical progress seen from a global perspective. In order to separate cyclical movements in output per employee from longer-run improvements in factor productivity, the U.S. series used to define the convergence path is a smooth trend based on the average growth of the U.S. series over the sample period.[10]

[8] E.g., those reported in Chenery, Robinson, and Syrquin (1986) and in section 2 of Helliwell and Chung (1988).

[9] The data sources are described in more detail in appendix A. The PPP exchange rates are the 1985-base calculations (Blades and Roberts 1987), which are collaboratively produced by the national statistical agencies and based on the U.N. program described in Kravis, Heston, and Summers (1978) and in Kravis and Lipsey (1989), and on previous OECD efforts reported by Hill (1986).

[10] The constant U.S. trend series is used to derive the technical progress indexes for the convergence models, as outlined in Appendix A. We also test several competing models of tech-

Following Gordon and Baily (1989), the algebraic form of the basic hypothesis of asymptotic convergence of country *i's* productivity growth rate to that of the United States is specified as follows:

$$(1) \qquad d\ln(\pi_{i,t}/\pi_{us,t}) = c_i + \alpha_i(\ln\pi_{us,t} - \ln\pi_{i,t-1})$$

where d is the first-difference operator; ln is the natural log; π_i is country *i's* productivity level; and α_i is the country-specific rate of convergence of country *i's* productivity level to that of the United States. The constant term c_i is equal to $-\alpha_i$ times the proportion by which, after the convergence process is complete, the U.S. productivity level in year t exceeds that in country i in the preceding year. Equation (1), as it stands, is not suitable for estimation, since the productivity indexes are not observed variables. For estimation purposes we use the time series for output attributable to each employee, calculated as described in appendix A, by inverting the production function and attributing a sample-average rate of return to the capital stock.[11] The logarithmic level form of the dependent variable is estimated, with the coefficient on the lagged dependent variable constrained to equal 1.0 on the right-hand side.[12] The initial estimation equations are thus:

$$(2) \qquad \ln(\pi_{m,i,t}/\pi_{m,us,t}) = \ln(\pi_{m,i,t-1}/\pi_{m,us,t-1}) + c_i + \alpha_i(\ln\pi_{m,us,t} - \ln\pi_{m,i,t-1}) + u_{i,t}$$

Where $\ln\pi_m$ is the log of measured output attributable per worker and the $u_{i,t}$ are disturbance terms.[13] These disturbances are assumed to have classical properties for individual countries, but the possibility of contemporaneous

---

nical progress against the maintained hypothesis of constant U.S. growth. These include a declining growth model which tests the possibility, emphasized by Nordhaus (1982), that there also has been a steady decline in the longer-run rate of technical progress in the United States, due to the depletion of natural resources and other factors that supported rapid growth in the early part of the sample period. We also test a popular form of this model in which longer-term productivity grows at a slower rate in and after 1974.

[11] With a Cobb-Douglas production function, this series only differs by a constant term from the total-factor index of technology often referred to as the Solow residual, based on the influential analysis in Solow (1957).

[12] The constraint of 1.0 on the lagged dependent variable implies that the estimates of coefficients and standard errors are not affected by the choice between the level or first difference of the logarithm of the measured productivity index as the dependent variable. Note that only the r-squares differ when the logarithmic level, rather than the logarithmic change, is used as the dependent variable in estimation.

[13] The algebraic form used eliminates the effects of cyclical variance common to country i and the United States. Equation (2) differs from the form used in both an earlier version of this paper and in Helliwell and Chung (1988), where the logarithm of the measured productivity index was regressed on its lagged value and a constant-growth U.S. trend index, with the coefficients restricted to sum to one. The current form was chosen because the output equations using efficiency indexes derived using equation (2) fit somewhat better. The estimated catch-up coefficients are also slightly lower than with our previous specification. An alternative method of adjusting for estimation bias caused by the cyclical variance in the measured series for output attributable to labor, which also gives slower rates of convergence, is reported in table 3 of Helliwell, Sturm, Jarrett, and Salou (1986).

cross-country error covariance is allowed for by the use of the Zellner seemingly unrelated regression (SUR) estimator, which also facilitates the imposition and testing of coefficient restrictions across countries.

Table 11.1 shows the results of fitting equation (2) for each of the eighteen industrial countries (the United States is excluded). If there were no evidence of convergence, the log ratio ln $(\pi_{m,us,t}/\pi_{m,i,t-1})$ would have a zero coefficient, and the constant term would measure the difference between the longer-run trends of technical progress in country i and in the United States. The results appear to show strong evidence of convergence, with positive coefficients on the log ratio in all countries, with t-values above 2.0 in all but five countries and exceeding 3.0 in a third of them.[14] However, with coefficients ranging from .03 for Norway to .17 for Sweden, there appear to be substantial international differences in the rates at which the countries are converging. The constant terms suggest that for almost two-thirds of the countries, the estimated level of the asymptotic growth path for capital-adjusted labor productivity is not significantly different from that of the United States, while in the rest it remains below U.S. productivity.[15]

The convergence process implied by equation (2) involves relatively easy international transmission of technical progress, so that a good part of the early-1960s gap between U.S. and foreign productivity levels is closed by 1985. A rather different view of the external effects of technical progress is assumed by Romer (1986), in which there are external economies of technical progress available to other firms operating in the domestic economy, but not to firms operating in other countries. This implies an element of increasing returns at the national level (in terms of aggregate GDP, rather than, as sometimes inferred, in terms of GDP per capita). The largest economies would gain the most from the external economies and would hence have continuing

---

[14] Despite the strong results, it is important to note that the success of the equations in explaining the trends in technical progress is not determined by the fit of the equations explaining measured productivity growth, because of the strong cyclical variance of measured productivity growth, but by the fit of the derived equations for output and factor demands.

[15] The coefficient α_i in equation (2) is an estimate of the annual proportionate rate at which the existing gap between U.S. and country i productivity levels is closed. The coefficient α_i and constant term c_i can be combined to calculate the change in efficiency level for any country i in a given year. For example, Norway has a relatively low value of α_i (.0364) and a small negative constant term (−.0093). In 1990, its productivity change is calculated to be 1.51 percent and its productivity level to be 63 percent of that of the United States. Sweden has a much higher value for α_i (.1695) offset by a larger negative constant term (−.1017), which together give a 1990 productivity change of 0.74 percent and a level equal to 55 percent of that of the United States. The high catch-up coefficient implies that Swedish productivity levels initially rise then grow at U.S. rates, while remaining below U.S. levels. Thus by 1990, the Swedish productivity level is already near its final ratio to the U.S. value. For Sweden and others (e.g., Japan at 62 percent in 1990) whose productivity levels converge to levels lower than one would expect, restricting the constant term to zero (which implies that productivity levels for all countries will eventually converge to U.S. levels) would probably provide more plausible forecasts. Using this alternative model, Sweden's 1990 productivity level is calculated to have reached 64 percent of the U.S. level, while Japan's level is calculated to be 76 percent of the U.S. level.

Table 11.1 **The Catch-up Model of Technical Progress**

	ln (π_{mi-1}/π_{mus-1})	ln (π_{mus}/π_{mi-1})	Constant	SEE	R^2	Durbin-Watson
Japan	1.0000	0.1089	−0.0503	0.0362	0.9782	1.7087
	(***)	(5.95)	(3.21)			
West Germany	1.0000	0.0641	−0.0234	0.0282	0.9725	1.4658
	(***)	(2.87)	(1.55)			
France	1.0000	0.0778	−0.0248	0.0273	0.9851	1.2160
	(***)	(5.43)	(2.39)			
United Kingdom	1.0000	0.0607	−0.0379	0.0310	0.8769	1.7277
	(***)	(1.12)	(0.96)			
Italy	1.0000	0.1215	−0.0591	0.0375	0.9678	1.4089
	(***)	(5.54)	(3.57)			
Canada	1.0000	0.0739	−0.0134	0.0209	0.9550	0.8804
	(***)	(2.73)	(1.54)			
Australia	1.0000	0.0978	−0.0383	0.0288	0.8583	1.6486
	(***)	(1.81)	(1.50)			
Austria	1.0000	0.0798	−0.0431	0.0389	0.9640	1.5667
	(***)	(3.61)	(2.27)			
Belgium	1.0000	0.0607	−0.0137	0.0329	0.9687	1.7974
	(***)	(2.90)	(1.07)			
Denmark	1.0000	0.0679	−0.0346	0.0301	0.9388	2.3499
	(***)	(1.99)	(1.33)			
Finland	1.0000	0.0578	−0.0333	0.0407	0.9560	1.6772
	(***)	(2.36)	(1.37)			
Ireland	1.0000	0.0573	−0.0337	0.0463	0.9589	1.6982
	(***)	(1.93)	(1.08)			
Netherlands	1.0000	0.0577	−0.0045	0.0339	0.9619	1.4992
	(***)	(2.20)	(0.40)			
New Zealand	1.0000	0.1295	−0.0544	0.0391	0.6684	1.2372
	(***)	(2.47)	(2.66)			
Norway	1.0000	0.0364	−0.0093	0.0311	0.9474	1.9688
	(***)	(1.08)	(0.39)			
Spain	1.0000	0.0752	−0.0196	0.0315	0.9843	1.7462
	(***)	(4.93)	(1.57)			
Sweden	1.0000	0.1695	−0.1017	0.0385	0.7750	1.9567
	(***)	(3.21)	(2.91)			
Switzerland	1.0000	0.1337	−0.0431	0.0334	0.8197	1.8392
	(***)	(2.77)	(2.23)			

Note: The dependent variable for each non-U.S. country i is specified in logarithmic level form as ln (π_{mi}/π_{mus}). The variable π_{mi} is the measured output attributable to labor for each country i, and π_{mus} is the U.S. measured value. The coefficient on the lagged dependent variable is constrained to equal 1.0, so that the logarithmic change in the dependent variable is estimated. The independent variable for each country is the logarithm of U.S. measured output attributable to labor divided by the lagged measured value for each country. See the section on specification in appendix B for a more complete description. Estimation was by Zellner's SUR estimation technique using sample 1961–85. The numbers in parentheses are absolute values of t-statistics, with *** denoting a constrained coefficient.

reductions in their relative costs. If the largest economy is also the one with the highest income per capita, as was the case in the 1960 to 1985 period being studied, then divergence might be expected, rather than the convergence we have modeled. It is possible to make a direct test of the importance of national returns to scale by adding to equation (2) the logarithm of a smoothed average of the ratio of each country's GDP to that of the United States. A coefficient value of $-.075$ ($t = -3.57$) is obtained when the variable is constrained to have the same coefficient across equations, suggesting that there are not technology-improving returns to scale at the national level. Thus, we feel more secure in continuing to model convergence based on the assumed international transfer of best-practice methods and techniques. We next turn to consider whether the pace of such transfer is related to some measure of relative openness.

Table 11.2 extends the basic convergence hypothesis by adding a variable representing the increase in each country's openness to foreign trade, as measured by the increase in its five-year moving average ratio of foreign trade to GDP. The cross-sectional hypothesis being tested here is that convergence is likely to be more rapid for countries that have increased their international linkages, with trade being used as an easily available proxy measure. The functional form used implies that it is proportionate changes in the trade share that affect the productivity level, and that the equilibrium efficiency level will be unaffected by the level of the equilibrium trade share.[16] The results reported in table 11.2 show that the openness variable attracts a significant positive constrained coefficient, with the coefficient value constrained to be the same for all countries to capture the cross-sectional effect. This supports the hypothesis that productivity growth has been faster in countries that have increased their openness to foreign trade. Subsidiary tests show that this effect is strongest in Europe and is weaker and sometimes perversely signed for countries outside Europe. The more restricted version embodied in Table 11.2 will be used for the further tests reported later.

Systematic tests of the two versions of the convergence model, as shown in tables 11.1 and 11.2, against alternative models are in tables 11.6 to 11.8. The two alternative models considered are the "constant" case (table 11.3) and the "break" case (table 11.4). The former involves the assumption that Harrod-neutral technical progress follows a constant rate in each country, while the rate differs among countries. In the "break" model, there are two separate rates of technical progress for each country, one applicable from 1960

---

[16] 16. Tests of an alternative functional form, where the efficiency level was influenced by the level of the trade share, as reported in Helliwell and Chung (1988), produced inferior results. Following a suggestion by Robert Lipsey, we have also tested a measure of openness based on the residuals from an equation that explains trade shares by country size and a trend, with the latter constrained to have the same coefficient for all countries. The resulting measure of residual openness attracted a positive but insignificant coefficient when added, along with the change in openness, to equation (2), and hence has not been used in our subsequent tests.

Table 11.2 **The Effects of Globalization on the Catch-up Model**

	$\ln(\pi_{mi-1}/\pi_{mus-1})$	$\ln(\pi_{mus}/\pi_{mi-1})$	DOPENA	Constant	SEE	R^2	Durbin-Watson
Japan	1.0000	0.0971	0.4971	−0.0521	0.0336	0.9751	1.7886
	(***)	(4.49)	(10.18)	(3.00)			
West Germany	1.0000	0.0527	0.4971	−0.0276	0.0252	0.9756	1.9740
	(***)	(2.33)	(10.18)	(1.89)			
France	1.0000	0.0755	0.4971	−0.0395	0.0223	0.9883	1.8298
	(***)	(5.82)	(10.18)	(4.35)			
United Kingdom	1.0000	0.0771	0.4971	−0.0547	0.0280	0.9016	1.9760
	(***)	(1.49)	(10.18)	(1.46)			
Italy	1.0000	0.0883	0.4971	−0.0523	0.0334	0.9682	1.6637
	(***)	(3.76)	(10.18)	(3.15)			
Canada	1.0000	0.0688	0.4971	−0.0215	0.0215	0.9488	0.9666
	(***)	(2.19)	(10.18)	(2.24)			
Australia	1.0000	0.1222	0.4971	−0.0516	0.0305	0.8285	1.6672
	(***)	(2.05)	(10.18)	(1.86)			
Austria	1.0000	0.0789	0.4971	−0.0535	0.0353	0.9668	1.8758
	(***)	(3.66)	(10.18)	(2.99)			
Belgium	1.0000	0.0430	0.4971	−0.0139	0.0300	0.9713	2.2481
	(***)	(1.99)	(10.18)	(1.12)			
Denmark	1.0000	0.0396	0.4971	−0.0232	0.0290	0.9367	2.4740
	(***)	(1.08)	(10.18)	(0.86)			
Finland	1.0000	0.0514	0.4971	−0.0326	0.0384	0.9577	1.8390
	(***)	(1.98)	(10.18)	(1.30)			
Ireland	1.0000	0.0577	0.4971	−0.0478	0.0498	0.9507	1.6097
	(***)	(1.53)	(10.18)	(1.24)			
Netherlands	1.0000	0.0392	0.4971	−0.0059	0.0279	0.9709	2.0922
	(***)	(1.78)	(10.18)	(0.64)			
New Zealand	1.0000	0.1230	0.4971	−0.0600	0.0388	0.6313	1.3045
	(***)	(2.14)	(10.18)	(2.63)			
Norway	1.0000	−0.0350	0.4971	0.0345	0.0299	0.9485	2.0673
	(***)	(1.06)	(10.18)	(1.53)			
Spain	1.0000	0.0336	0.4971	−0.0132	0.0335	0.9787	1.6343
	(***)	(1.67)	(10.18)	(0.87)			
Sweden	1.0000	0.1487	0.4971	−0.0951	0.0381	0.7440	2.0195
	(***)	(2.54)	(10.18)	(2.51)			
Switzerland	1.0000	0.1229	0.4971	−0.0492	0.0310	0.8343	2.0103
	(***)	(2.63)	(10.18)	(2.69)			

Note: This model is specified in the same way as the catch-up model in Table 11.1, but it includes the additional variable DOPENA. DOPENA is the annual change in "openness" defined as the log difference of current and lagged values of the five-year moving average of exports plus imports divided by GNP. See the section on specification in appendix B for a more complete description. Estimation was by Zellner's SUR estimation technique using sample 1963–85.

Table 11.3 **The Constant Model of Technical Progress**

	RTIME	Constant	SEE	R^2	Durbin-Watson
United States	0.0072	33.4020	0.0414	0.6331	0.3284
	(6.70)	(423.48)			
Japan	0.0408	30.2260	0.1078	0.8894	1.1356
	(14.46)	(147.11)			
West Germany	0.0295	31.1750	0.0462	0.9582	0.2292
	(24.41)	(354.14)			
France	0.0371	30.6200	0.0699	0.9408	0.0876
	(20.33)	(229.90)			
United Kingdom	0.0170	31.9880	0.0376	0.9198	0.5007
	(17.27)	(445.85)			
Italy	0.0350	30.7230	0.0924	0.8896	0.1311
	(14.47)	(174.47)			
Canada	0.0193	32.2570	0.0445	0.9131	0.2151
	(16.53)	(379.93)			
Australia	0.0164	32.2880	0.0406	0.9024	0.4871
	(15.50)	(417.60)			
Austria	0.0338	30.010	0.0612	0.9451	0.1297
	(21.16)	(263.30)			
Belgium	0.0316	31.1250	0.0462	0.9634	0.2327
	(26.16)	(353.71)			
Denmark	0.0237	31.4890	0.0492	0.9287	0.3029
	(18.41)	(335.75)			
Finland	0.0327	30.6430	0.0459	0.9661	0.3588
	(27.24)	(350.52)			
Ireland	0.0367	30.2820	0.0505	0.9675	0.5218
	(27.82)	(314.71)			
Netherlands	0.0296	31.4430	0.0500	0.9516	0.2528
	(22.60)	(329.66)			
New Zealand	0.0018	33.4420	0.0524	0.0645	0.4934
	(1.34)	(334.86)			
Norway	0.0251	31.4520	0.0288	0.9770	0.6848
	(33.25)	(572.53)			
Spain	0.0423	30.1740	0.0670	0.9573	0.2139
	(24.16)	(236.40)			
Sweden	0.0174	32.0350	0.0482	0.8792	0.3070
	(13.75)	(348.41)			
Switzerland	0.0163	32.3790	0.0542	0.8361	0.1858
	(11.52)	(313.38)			

Note: The dependent variable is ln π_m, measured output attributable to labor. RTIME is an annual time trend equal to 60 in 1960, 61 in 1961. See the section on specification in appendix B for a more complete description. Estimation was by Zellner's SUR estimation technique using sample 1960–85.

Table 11.4 **The "Break" Hypothesis**

	RTIME	T74	Constant	SEE	R^2	Durbin-Watson
United States	0.0163	−0.0071	32.8140	0.0280	0.8318	0.6124
	(9.11)	(5.54)	(276.22)			
Japan	0.0657	−0.0196	28.6030	0.0675	0.9566	0.5292
	(15.25)	(6.35)	(99.92)			
West Germany	0.0362	−0.0053	30.7360	0.0402	0.9683	0.3431
	(14.13)	(2.89)	(180.36)			
France	0.0477	−0.0083	29.9300	0.0601	0.9563	0.2098
	(12.46)	(3.03)	(117.52)			
United Kingdom	0.0192	−0.0017	31.8430	0.0369	0.9230	0.5021
	(8.17)	(1.04)	(203.59)			
Italy	0.0515	−0.0130	29.6450	0.0736	0.9299	0.3602
	(10.97)	(3.87)	(94.98)			
Canada	0.0230	−0.0029	32.0150	0.0427	0.9200	0.2345
	(8.43)	(1.50)	(176.67)			
Australia	0.0247	−0.0065	31.7510	0.0295	0.9482	1.0096
	(13.10)	(4.80)	(253.52)			
Austria	0.0410	−0.0056	30.2360	0.0562	0.9536	0.2443
	(11.42)	(2.18)	(126.81)			
Belgium	0.0371	−0.0044	30.7620	0.0422	0.9694	0.3152
	(13.80)	(2.27)	(172.01)			
Denmark	0.0337	−0.0078	30.8400	0.0359	0.9620	0.7215
	(14.68)	(4.77)	(202.34)			
Finland	0.0390	−0.0049	30.2320	0.0406	0.9734	0.4968
	(15.03)	(2.67)	(175.42)			
Ireland	0.0346	0.0017	30.4220	0.0500	0.9682	0.5372
	(10.85)	(0.74)	(143.60)			
Netherlands	0.0352	−0.0044	31.0770	0.0463	0.9585	0.3985
	(11.92)	(2.09)	(158.30)			
New Zealand	0.0062	−0.0034	33.1610	0.0503	0.1366	0.6051
	(1.92)	(1.47)	(155.37)			
Norway	0.0262	−0.0009	31.3770	0.0286	0.9774	0.7505
	(14.39)	(0.69)	(259.13)			
Spain	0.0514	−0.0071	29.5820	0.0595	0.9663	0.3745
	(13.53)	(2.63)	(117.18)			
Sweden	0.0258	−0.0066	31.4840	0.0389	0.9215	0.7236
	(10.40)	(3.74)	(190.91)			
Switzerland	0.0287	−0.0097	31.5770	0.0348	0.9324	0.9470
	(12.90)	(6.08)	(213.86)			

Note: The dependent variable is ln π_m, measured output attributable to labor. RTIME is an annual time trend equal to 60 in 1960, 61 in 1961. T74 is a time trend equal to zero before 1974 and equal to 1 in 1974, 2 in 1975. See the section on specification in appendix B for a more complete description. Estimation was by Zellner's SUR estimation technique using sample 1960–85.

to 1973, and the second applicable thereafter, to embody the frequently noted post-1973 slowdown of output growth in the industrial countries (e.g., Bruno and Sachs 1985).[17] Before 1974, the average rate is shown as the coefficient on RTIME in table 11.4, while for 1974 and after, the rate is adjusted by the value of the coefficient on the auxiliary time trend T74. In each country, there was an apparent reduction in the average annual rate of technical progress after 1973, (with a *t*-value above 2.0 in all but five countries), by an amount averaging about 0.6 percentage points or roughly just under a fifth of the average pre-1974 rate of technical progress.

To provide a test of the productivity models estimated for the constant, break, and convergence cases, it is necessary to derive noncyclical indexes of technical progress for each of the models. The indexes can then be used comparably in equations that attempt to explain the actual movements of output in terms of the underlying production function (including the alternative derived series for technical progress) and other short-term demand and profitability factors possibly causing temporary departures from the normal productivity performance. As explained in appendix B, the technical progress indexes for the convergence models are calculated cumulatively, starting from a base chosen so that the calculated labor productivity index should equal the measured values on average, without any of the cyclical variance present in the measured values of the series for capital-adjusted output per employee.

The output equation used for the non-nested tests of the alternative indexes of technical progress is the factor utilization model, as described in Helliwell and Chung (1986). This approach treats the output decision of the representative firm as depending on its employed stocks of labor and capital (including explicit allowance for technical progress, based on whatever model of technical progress is being assumed), conditioned by unexpected sales, profitability, and inventory disequilibrium.[18] In this framework, the employed stocks of labor and capital, when combined with the index of technical progress in the synthetic production function, represent the expected level of demand to the extent that firms foresaw it as being sufficiently profitable and permanent to justify changes in investment and employment. Temporary and unexpected changes in demand and cost conditions are then accommodated partially by changes in the intensity of factor use[19] and partially by price changes. Inven-

---

[17] A catch-up model was also subsequently tested which included, as an additional explanatory variable, a separate break term set equal to one from 1974, and to zero from 1960 to 1973. The break term was not significantly different from zero when constrained across equations, and hence we chose not to pursue this case further.

[18] As shown in Helliwell (1986), this formulation is general enough to include the Lucas (1973), Barro (1978), and Keynesian output functions as nested hypotheses. The tests reported there showed that the more general formulation of the factor utilization approach rejected the more restricted models when fitted to data from each of the G-7 economies. Comparisons with the technology shock approach frequently used in real business models will be presented in section 11.4.

[19] The use of buffering changes in factor utilization, with recognition that the usage of both labor and capital can be shifted back and forth between direct production and maintenance activi-

tories then act as a buffer for any residual excess demand or supply, to an extent that is influenced by the current discrepancy between the actual and normal ratios of inventory stocks to expected sales.

The output equation tests for the United States are reported in table 11.5, while those for all the industrial countries are reported in table 11.6.[20] For the United States, four competing models of technical progress are tested. These models are the constant productivity growth model, the constant growth model adjusted for the post-1974 productivity break, the constant growth model adjusted for the effects of increased openness, and a declining growth model.[21] Overall, the tests reject the break model, shown by the significant additional information provided by the competing models in the *P* test, and by the lower *C*-test coefficients for the break model when it is compared directly with each alternative model.[22] The *C* test indicates weak preference for the constant growth model over the model including the effects of increased openness, but it does not provide much guidance in choosing between the constant growth and declining growth models. The Godfrey tests do not support one particular model. For the convergence models reported in this paper, we therefore have chosen the constant model for the United States to derive the non-U.S. technical progress indexes.[23]

To summarize the output equation tests reported in table 11.6, the constant and break models of technical progress are very strongly rejected in favor of either of the convergence models.[24] Of the two convergence models, the

---

ties, is also starting to appear in real business cycle models, e.g., Greenwood, Hercowitz, and Huffman (1988).

[20] Note that the parameter estimates for the output equations, assuming the convergence model for the non-U.S. countries and constant growth of technical progress for the United States, are shown in table 11.9.

[21] The declining growth model uses a trend which declines by 30 percent over the 25-year sample period (as described in appendix B). The 30 percent declining growth model produced the output equation with the best fit when several alternative rates of decline were tested. Compared with the constant growth model, which has an efficiency index that grows at .73 percent per year throughout the sample, the 30 percent declining growth model produces a U.S. efficiency index that grows at an average rate of .81 percent for the period 1961–73, .67 percent for the period 1974–85, and .54 percent for the period 1985–2000.

[22] Note that the *P* and *C* tests are described near the end of tables 11.5 and 11.6, and that the Godfrey test is described at the bottom of table 11.5.

[23] Tests of convergence assuming a 30 percent declining growth model for the United States indicated that the output equations for the non-U.S. group of countries prefer the declining growth model. These new tests thus provide further support for one surprising feature of our earlier results: that most countries outside the United States show evidence of a convergence process that is projected to leave non-U.S. productivity levels below, and sometimes well below, those in the United States. Post-1985 data will help to show whether this is a continuing feature of the evidence or is due to the widespread recessions in the first half of the 1980s.

[24] A declining growth model for all countries was later tested to examine whether there has been a steady decline in the longer-run rate of technical progress, as suggested by Nordhaus (1982). The 30 percent declining trend was used, as this trend was favored for the United States. The *C* tests of the non-U.S. output equations indicated that both convergence models were strongly preferred to the declining growth model, and that the declining growth model was preferred to the constant growth and "break" models. Thus for the current data sample, the non-U.S.

model without openness effects is preferred. This suggests that the openness effects are potentially important, but that the current specification does not quite capture them.[25]

Tables 11.7 and 11.8 extend the tests to include the derived investment and labor demand equations. These equations show much less power to discriminate among the different models of technical progress. In the case of the investment equations, for which the tests are reported in table 11.7, the *F*-statistics show that none of the four models can simultaneously reject all of the other three. As for the pattern among the models, the catch-up and break models are clearly the worst, and the constant model less clearly the best; the convergence model with openness effects falls in between. For the derived employment equations, the *F*-statistics show the catch-up model to be the least sufficient of the models, and the catch-up model with openness effects to be slightly better than the constant model, which is preferred to the break model. Although the statistical significance of these results is far less than for the comparison of the alternative output equations, they do tend to confirm the rejection of the break model, while qualifying the dominance of the convergence models over the model assuming constant technical progress.

Table 11.9 reports parameter estimates for the output equations of the industrial countries. Constant growth of technical progress is assumed for the United States and the convergence model is assumed for the non-U.S. countries. The results provide evidence that for the majority of countries, output is significantly affected by unexpected sales, profitability, and inventory disequilibrium.

11.3 Issues of Data and Measurement

In this section we emphasize issues of data and measurement, through the use of three sorts of sensitivity test. In section 11.3.1, we consider the consequences of using PPP rather than market exchange rates, while in section 11.3.2 we test the effects of adopting alternative measures of the aggregate

---

countries generally prefer some slowdown, as evidenced by the relatively good performance of the convergence and declining growth models. Although our current results show that the convergence models contain more information than the declining growth model, they also warrant further investigation, using models with possibly a broader range of targets for convergence, and estimating over a longer sample period.

[25] A supplementary test of the output equations using the two convergence models was also done, and this showed the pure catch-up model to out-perform only slightly the model with openness effects. The investment and employment equations estimated under each model were used to derive predicted values for the factor demands. The predicted capital stock and employment series were then placed in the CES production function to calculate an alternative normal output (q_s) series for each country, and the output equations were reestimated as before. *C* tests of these new output equations showed that the catch-up model with openness effects was only marginally inferior to the pure catch-up model. These results thus illustrate the potential importance of the former model, given the superior fit of its estimated factor demands.

Table 11.5 **Non-nested Tests of U.S. Output Equations**

The following models of labor productivity were estimated and tested using non-nested tests of the U.S. output equations. H_0 denotes the maintained hypothesis, which is tested against the competing models. The output equations were estimated by two-stage least squares over the sample 1963–85 for all models. See appendix B for variable definitions.

Case 1: H_0: Constant case: $\ln \pi_m = a_1\text{RTIME} + c$
H_1: Break case: $\ln \pi_m = a_1\text{RTIME} + a_2\text{T74} + c$
H_2: Open case: $\ln \pi_m = a_1\text{RTIME} + a_2\text{DOPENA} + c$
H_3: Decline Case: $\ln \pi_m = a_1\text{DECLINE} + c$

Case 2: H_0:	Break	*Case 3:* H_0:	Open	*Case 4:* H_0:	Decline
H_1:	Constant	H_1:	Constant	H_1:	Constant
H_2:	Open	H_2:	Break	H_2:	Break
H_3:	Decline	H_3:	Decline	H_3:	Open

(1) *P* Test

	t-statistics			
	Case 1	Case 2	Case 3	Case 4
H_1	.06278	2.5821*	1.07290	1.07720
H_2	.45623	2.3831*	.05634	.06300
H_3	.97296	2.5174*	.96835	.45631

Note: Because of collinearity between H_1 and H_2, each hypothesis was tested in separate regressions for case 2.
* = significance at the 95% level.

	F-statistics			
	Case 1	Case 2	Case 3	Case 4
$H_1 = H_2 = H_3 = 0$ (3,16) df	.43854		.67419	.55073
$H_1 = 0.0$ (1,16) df	.00394	6.66713* (1,18) df	1.15102	1.16027
$H_2 = 0.0$ (1,16) df	.20814	5.67904* (1,18) df	.00317	.00397
$H_3 = 0.0$ (1,16) df	.94665	6.33743* (1,18) df	.93769	.20822

* = rejection of the null hypothesis at 5% significance.

(2) *C* Test

	Coefficient	*t*-Ratio		Coefficient	*t*-Ratio
Case 1	.75144	2.71	Case 1	5.29500	1.04
Case 2	.24856	.90	Case 4	−4.29500	.84
Case 1	.83329	1.42	Case 2	.26871	.98
Case 3	.16671	.28	Case 4	.73129	2.66
Case 2	.37684	1.61	Case 3	.20768	.34
Case 3	.62316	2.66	Case 4	.79232	1.29

Table 11.5 **(continued)**

	(3) Godfrey Test			
	Case 1	Case 2	Case 3	Case 4
H_1	.4383	1.5259	.38028	.41335
H_2	1.5333	1.0676	.44562	.48691
H_3	.2668	1.4982	.56077	1.63110

Test Methods:

(1) *P* Test: Following Davidson and MacKinnon (1981), the following procedure was used. Given two alternative models,

$$H_0\colon Yt = ft\,(Xt,\,\beta) + e0t$$
$$H_1\colon Yt + gt\,(Zt,\,\gamma) + e1t,$$

the following artificial regression can be estimated for the *P* test:

$$Yt - fht = b\,Xt = \lambda\,(ght - fht)$$

where *fht* and *ght* denote the fitted values based on H_0 and H_1. The *t* ratio for λ is the *P* test. If it is significant H_0 is rejected, and if insignificant H_0 is not rejected. In cases 1 and 3 above, H_0 was tested against more than one alternative hypothesis at a time, with joint *F*-statistics reported to test whether H_1 and H_2 are zero.

(2) *C* Test: Again following Davidson and MacKinnon (1981), the *C* test involves estimating the following regression:

$$Yt = \alpha\,fht + (1 - \alpha)\,ght$$

where *fht* and *ght* are the fitted values of *yt* from the two competing models. If α is greater than $(1 - \alpha)$ and is significant, then *fht* is the dominating model.

(3) Godfrey Test: The statistics are derived using Godfrey's (1983) test of competing non-nested models estimated by an instrumental (IV) estimator (e.g., two-stage least squares). Let the two models be

$$H_0\colon Yt = ft\,(Xt,\,\beta) + e0t$$
$$H_1\colon Yt = gt\,(Zt,\,\gamma) + e1t$$

and let *W* be the set of exogenous variables included in the two-stage least squares estimation. We first estimate H_0 and H_1 by two-stage least squares and obtain the sample values of *b* and *c* (the two-stage least squares estimates of β and γ given *W*). We calculate the ordinary least squares predicted values *Xht* and *Zht* from the regression of *X* and *Z* on *W*. We then obtain the residual vector from the ordinary least squares regression of *Xht b* on *Zht* and add it as an independent variable in the regression of the maintained hypothesis. The table reports the *t*-statistic for the variable. If it is significant, it indicates that H_1 adds significant explanatory power to H_0 and it implies the rejection of the null hypothesis against H_1.

capital stock in the specification of the aggregate technology. Finally, in section 11.3.3 we present some preliminary evidence with an alternative production model in which technical progress is embodied in capital via gross investment.

11.3.1 Exchange Rates and the Convergence of Productivity Levels

In the productivity comparisons of this paper, the OECD 1985-based PPP exchange rates for GDP are used to convert real values (in terms of national currencies at constant prices) into "international dollars." What difference would it make if market exchange rates were used instead? The answer to this question depends on the year chosen for the conversion base, since the departures of market exchange rates from PPP differ considerably from year to year. To test the impact of using market rather than PPP exchange rates, we can refit

Table 11.6 Non-nested Tests of Output Equations for the Industrial Countries

The following models of labor productivity were estimated and tested using non-nested tests of the output equations for the 19 industrial countries. For all non-break models, the constant case is used for the U.S. In the break base, the break model is used for U.S. and non-U.S. models, consistent with the hypothesis that the productivity slowdown was a feature of all the industrial countries. In the tests below, H_0 denotes the maintained hypothesis, which is tested against the competing models. The output equations were estimated by Zellner seemingly-unrelated regression technique with instrumental variables, using the sample period 1963–85 for all models.

Case 1: H_0: Pure catch-up case: $\text{dln}\ (\pi_m/\pi_{mus}) = a_1 \ln (\pi_{mus}/\pi_{m-1}) + a_2$
H_1: Catch-up with openness: $\text{dln}\ (\pi_m/\pi_{mus}) = a_1 \ln (\pi_{mus}/\pi_{m-1}) + a_2\text{DOPENA} + a_3$
H_2: Constant case: $\ln \pi_m = a_1\text{RTIME} + a_2$
H_3: Break case: $\ln \pi_m = a_1\text{RTIME} + a_2\text{T74} + a_3$

Case 2: H_0: Catch-up/open
H_1: Pure Catch-up
H_2: Constant
H_3: Break

Case 3: H_0: Constant
H_1: Catch-up
H_2: Catch-up/open
H_3: Break

Case 4: H_0: Break
H_1: Catch-up
H_2: Catch-up/open
H_3: Constant

(1) *P* Test

	t-statistics			
	Case 1	Case 2	Case 3	Case 4
H_1	2.66*	4.86*	4.96*	5.09*
H_2	.54	.66	2.38*	2.24*
H_3	.29	.58	.78	.45

* = significance at the 95% level.

	F-statistics			
	Case 1	Case 2	Case 3	Case 4
$H_1 = H_2 = H_3 = 0$ (3,430) df	3.08*	8.42*	77.79*	91.44*
$H_1 = 0.0$ (1,430) df	7.07*	23.58*	24.61*	25.86*
$H_2 = 0.0$ (1,430) df	.29	.43	5.64*	5.04*
$H_3 = 0.0$ (1,430) df	.08	.34	.60	.21

* = rejection of the null hypothesis at 5% significance.

(2) *C* Test

	Coefficient	*t*-Ratio		Coefficient	*t*-Ratio
Case 1	.70399	5.94	Case 2	.85986	13.80
Case 2	.29601	2.50	Case 3	.14014	2.25
Case 1	1.08540	15.04	Case 2	.86829	15.14
Case 3	−.08540	1.18	Case 4	.13171	2.30

Table 11.6 **(continued)**

(2) C Test

	Coefficient	t-Ratio		Coefficient	t-Ratio
Case 1	1.06690	16.31	Case 3	.80523	5.33
Case 4	−.06690	1.02	Case 4	.19477	1.29

Note: Case 1 = Pure catch-up; Case 2 = Catch-up with openness; Case 3 = Constant; Case 4 = Break.

Test Methods:

(1) P Test: Following Davidson and MacKinnon (1981), the following procedure was used. Given two alternative models,

$$H_0\text{: } Yit = fit\,(Xt,\ \beta) + e0it$$
$$H_1\text{: } Yit = git\,(Zt,\ \gamma) + e1it,$$

(where i (= 1, m) indexes equations and t (= 1, n) indexes observations), the following artificial regression can be estimated for the P test:

$$Yit - fhit = b\,Xit = \lambda\ (ghit - fhit)$$

where $fhit$ and $ghit$ denote the fitted values based on H_0 and H_1. The t ratio for λ is the P test. If it is significant H_0 is rejected, and if insignificant H_0 is not rejected. In the results above H_0 was tested against more than one alternative hypothesis at a time, with F-statistics reported to test whether H_1, H_2, and H_3 are zero.

(2) C Test: Again following Davidson and MacKinnon (1981), the C test involves estimating the following regression:

$$Yit = \alpha\, fhit + (1 - \alpha)\, ghit$$

where $fhit$ and $ghit$ are the fitted values of yt from the two competing models. If α is greater than $(1 - \alpha)$ and is significant, then fit is the dominating model.

the models using market exchange rates for conversion. Then we will be able to see how the conclusions would differ about the extent to which the convergence model predicts international convergence of income levels, both between the United States and the converging countries as a group, and among the eighteen non-U.S. countries.

Table 11.10 shows the results of tests of productivity level convergence using the PPP and market rates (for both 1980 and 1985) to convert the real incomes and capital stocks.[26] The top half of the table shows the results of tests of the basic convergence model of table 11.1, and the bottom half shows the same tests for the model of table 11.2, which includes the productivity effects of increasing trade shares. The Wald test results show that the use of market rather than PPP exchange rates makes the most difference when the specification constrains the convergence models to have the same asymptotic level of productivity in each country. In these cases, there is significantly more evidence of convergence when PPPs rather than 1980 or 1985 market exchange rates are used. It is encouraging, for both the data and the convergence hypothesis, that the theoretically preferable PPP data provide stronger evi-

---

[26] Heston and Summers (1988, p. 471) note that PPPs for investment goods can be materially different from those for GDP; so we should in principle be using different PPPs for converting the real capital stocks into international dollars. Tests of this alternative have not yet been carried out.

Table 11.7 **Non-nested Tests of Investment Equations for the Industrial Countries**

The investment equations were estimated by Zellner Seemingly Unrelated Regression technique with instrumental variables, using the sample period 1963–85 for all models. The models of labor productivity are identical to those outlined in table 11.6.

(1) *P* Test

	t-statistics			
	Case 1	Case 2	Case 3	Case 4
H_1	2.63*	2.14*	2.62*	2.60*
H_2	3.89*	3.90*	3.89*	3.90*
H_3	1.24	1.24	1.24	1.21

* = significance at the 95% level.

	F-statistics			
	Case 1	Case 2	Case 3	Case 4
$H_1 = H_2 = H_3 = 0$ (4,430) df	9.35*	5.56*	9.36*	9.37*
$H_1 = 0.0$ (1,430) df	6.91*	4.59*	6.88*	6.78*
$H_2 = 0.0$ (1,430) df	15.14*	15.19*	15.17*	15.21*
$H_3 = 0.0$ (1,430) df	1.54	1.53	1.53	1.47

* = rejection of the null hypothesis at 5% significance.

(2) C Test

	Coefficient	*t*-Ratio		Coefficient	*t*-Ratio
Case 1	.15508	.66	Case 2	.34159	1.59
Case 2	.84492	3.61	Case 3	.65841	3.06
Case 1	−.45173	1.45	Case 2	.76096	3.64
Case 3	1.45173	4.67	Case 4	.23904	1.14
Case 1	.47991	1.96	Case 3	1.25870	4.45
Case 4	.52009	2.12	Case 4	−.25870	.91

Note: Case 1 = Pure catch-up; Case 2 = Catch-up with openness; Case 3 = Constant; Case 4 = Break

See note to table 11.6 for explanation of the test method used here.

Table 11.8 Non-nested Tests of Employment Equations for the Industrial Countries

The employment equations were estimated by Zellner Seemingly Unrelated Regression technique with instrument variables, using the sample period 1963–85 for all models. The models of labor productivity are identical to those outlined in table 11.6.

(1) *P* Test

	t-statistics			
	Case 1	Case 2	Case 3	Case 4
H_1	3.06*	1.86	1.77	1.79
H_2	1.85	1.85	3.06*	3.07*
H_3	.72	0.71	.74	1.85

* = significance at the 95% level.

	F-statistics			
	Case 1	Case 2	Case 3	Case 4
$H_1 = H_2 = H_3 = 0$ (3,432) df	7.95*	2.64*	3.78*	7.60*
$H_1 = 0.0$ (1,432) df	9.39*	3.48*	3.16*	3.20*
$H_2 = 0.0$ (1,432) df	3.42*	3.41*	9.39*	9.45*
$H_3 = 0.0$ (1,432) df	.52	.51	.55	3.41*

* = rejection of the null hypothesis at 5% significance.

(2) *C* Test

	Coefficient	*t*-Ratio		Coefficient	*t*-Ratio
Case 1	−.74296	1.84	Case 2	.50092	2.15
Case 2	1.74296	4.32	Case 3	.49908	2.14
Case 1	.16620	.79	Case 2	.76455	3.40
Case 3	.83380	3.97	Case 4	.23545	1.05
Case 1	.39331	1.83	Case 3	1.0697	3.23
Case 4	.60669	2.82	Case 4	−.0697	.21

Note: Case 1 = Pure catch-up; Case 2 = Catch-up with openness; Case 3 = Constant; Case 4 = Break

See note to table 11.6 for explanation of the test method used here.

Table 11.9 **Output Equations for Industrial Countries (using Catch-up Model for non-U.S.)**

	LNQS	LNCQ	LNSGAP	LNIGAP	SEE	R^2	Durbin-Watson
United States	1.0000	−0.1823	0.7039	0.0142	0.0085	0.9979	0.7797
	(***)	(11.93)	(19.32)	(4.42)			
Japan	1.0000	−0.0828	0.8035	0.0142	0.0075	0.9996	0.8851
	(***)	(8.27)	(32.69)	(4.42)			
West Germany	1.0000	−0.1097	0.6287	0.0142	0.0096	0.9978	1.1195
	(***)	(5.48)	(23.60)	(4.42)			
France	1.0000	−0.1764	0.8386	0.0142	0.0112	0.9981	0.6021
	(***)	(12.80)	(27.50)	(4.42)			
United Kingdom	1.0000	0.0170	0.4606	0.0142	0.0208	0.9758	0.5232
	(***)	(0.78)	(7.51)	(4.42)			
Italy	1.0000	−0.0171	0.9006	0.0142	0.0143	0.9964	0.3015
	(***)	(1.43)	(30.55)	(4.42)			
Canada	1.0000	−0.2793	0.6624	0.0142	0.0114	0.9985	0.6969
	(***)	(11.26)	(22.14)	(4.42)			
Australia	1.0000	−0.1316	1.1771	0.0142	0.0128	0.9972	1.0918
	(***)	(9.76)	(19.52)	(4.42)			
Austria	1.0000	−0.1009	0.6283	0.0142	0.0098	0.9984	0.6862
	(***)	(3.99)	(33.44)	(4.42)			
Belgium	1.0000	−0.0728	0.5889	0.0142	0.0087	0.9986	1.0531
	(***)	(4.66)	(26.65)	(4.42)			
Denmark	1.0000	−0.0877	0.4910	0.0142	0.0094	0.9968	1.1807
	(***)	(8.84)	(19.55)	(4.42)			
Finland	1.0000	0.0038	0.6342	0.0142	0.0133	0.9972	0.8017
	(***)	(0.27)	(18.57)	(4.42)			
Ireland	1.0000	0.0112	0.5677	0.0142	0.0288	0.9903	0.8485
	(***)	(0.26)	(9.99)	(4.42)			
Netherlands	1.0000	−0.0348	0.4984	0.0142	0.0102	0.9978	0.9815
	(***)	(2.26)	(29.36)	(4.42)			
New Zealand	1.0000	−0.0748	0.8826	0.0142	0.0155	0.9905	1.3872
	(***)	(5.45)	(28.10)	(4.42)			
Norway	1.0000	0.0074	0.2239	0.0142	0.0184	0.9954	0.8186
	(***)	(0.21)	(4.88)	(4.42)			
Spain	1.0000	−0.0155	0.5564	0.0142	0.0131	0.9978	0.6275
	(***)	(0.84)	(10.34)	(4.42)			
Sweden	1.0000	−0.0172	0.5554	0.0142	0.0108	0.9959	1.6575
	(***)	(1.04)	(15.11)	(4.42)			
Switzerland	1.0000	−0.2651	0.5239	0.0142	0.0219	0.9752	0.4475
	(***)	(5.23)	(10.28)	(4.42)			

Note: Sample 1963–85. Estimation method by Zellner's SUR estimation technique with instruments. The numbers in parentheses are absolute values of *t*-statistics, with *** denoting a constrained coefficient. LNQS is the logarithm of normal output, which is defined by the CES production function. LNCQ is the logarithm of the ratio of current unit cost relative to output price, which is an inverse measure of profitability. LNSGAP is the logarithm of the ratio of actual sales to normal sales. LNIGAP is the logarithm of the ratio of desired to lagged inventory stock.

Table 11.10 The Effects of using PPPs versus Market Exchange Rates

	Wald		χ^2
Tests of table 11.1 model using 1980 GDP PPPs:			
(a) Homogeneity of catch-up coefficients	59.64 (17df)	vs.	28.0
(b) Constants = 0.0	52.94 (18df)	vs.	28.9
(c) (a) + (b)	411.73 (35df)	vs.	43.8
(d) Constants equal for non-U.S.	47.31 (17df)	vs.	28.0
(e) (a) + (d)	400.60 (34df)	vs.	43.8
Tests of table 11.1 model using 1980 market exchange rates:			
(a) Homogeneity of catch-up coefficients	59.64 (17df)	vs.	28.0
(b) Constants = 0.0	120.17 (18df)	vs.	28.9
(c) (a) + (b)	555.21 (35df)	vs.	43.8
(d) Constants equal for non-U.S.	116.51 (17df)	vs.	28.0
(e) (a) + (d)	510.87 (34df)	vs.	43.8
Tests of table 11.1 model using 1985 market exchange rates:			
(a) Homogeneity of catch-up coefficients	59.64 (17df)	vs.	28.0
(b) Constants = 0.0	130.07 (18df)	vs.	28.9
(c) (a) + (b)	555.20 (35df)	vs.	43.8
(d) Constants equal for non-U.S.	128.04 (17df)	vs.	28.0
(e) (a) + (d)	511.48 (34df)	vs.	43.8
Tests of table 11.2 model using 1980 GDP PPPs:			
(a) Homogeneity of catch-up coefficients	82.47 (17df)	vs.	28.0
(b) Constants = 0.0	90.20 (18df)	vs.	28.9
(c) (a) + (b)	221.60 (35df)	vs.	43.8
(d) Constants equal for non-U.S.	63.92 (17df)	vs.	28.0
(e) (a) + (d)	221.60 (34df)	vs.	43.8
Tests of table 11.2 model using 1980 market exchange rates:			
(a) Homogeneity of catch-up coefficients	82.47 (17df)	vs.	28.0
(b) Constants = 0.0	106.86 (18df)	vs.	28.9
(c) (a) + (b)	267.63 (35df)	vs.	43.8
(d) Constants equal for non-U.S.	106.55 (17df)	vs.	28.0
(e) (a) + (d)	260.75 (34df)	vs.	43.8
Tests of table 11.2 model using 1985 market exchange rates:			
(a) Homogeneity of catch-up coefficients	82.47 (17df)	vs.	28.0
(b) Constants = 0.0	136.16 (18df)	vs.	28.9
(c) (a) + (b)	267.82 (35df)	vs.	43.8
(d) Constants equal for non-U.S.	121.29 (17df)	vs.	28.0
(e) (a) + (d)	261.63 (34df)	vs.	43.8

Note: The chi-square (χ^2) statistics in the above table are approximate.

dence in favor of the convergence hypothesis. This is true for both models assessed, and for comparisons including the United States as well as those among the converging countries other than the United States.[27]

11.3.2 Alternative Measures of the Aggregate Capital Stock

In this section we test the implications for the derived equations for the determination of aggregate output of using alternative measures of the capital stock. In the tests thus far, we have used the aggregate fixed capital stock, including business, housing, and government. In table 11.11 we show the output equations resulting if we instead employ the gross private stock of fixed capital (comprising business and housing). Table 11.12 shows the corresponding results using the stock of business fixed capital. As shown by the test comparisons in table 11.13, the results, in terms of the fit of the derived output equations, favor the use of the stock of business fixed capital over the other alternatives, and favor the private capital stock over the total stock.

The implied lower contribution of public and housing investment to subsequent levels of real GDP may reflect the nature of the data, as the GDP accounts do not take into direct account the value added by the public capital stock and the returns to the housing stock are heavily influenced by the assumptions about scrapping rates and the implied ownership return on the stock of owner-occupied housing.

We have also tested capital stock measures that include the stock of inventories along with one or more of the measures of the stock of fixed capital. As shown in table 11.14, for all three definitions of fixed capital, the models including inventories in the capital stock are inferior, in terms of the derived output equations, to the models based only on the fixed capital stocks.

11.3.3 Capital-Embodied Technical Progress

The models used thus far assume Harrod-neutral technical progress. The CES production function employed has a near-unitary elasticity of substitution between capital and labor, and hence there is little consequence, in terms of the variance of the synthetic output series, of attributing technical progress to labor rather than capital, so long as the progress accrues equally to new and existing capital. Potentially, it makes much more difference if one assumes that technical progress accrues only to the new vintages of capital and hence requires gross investment for its realization. Baily (1981) and others have suggested that the simultaneous post-1973 declines in both gross investment and observed productivity performance, in the aftermath of obsolescence-inducing increases in energy prices, indicate the likelihood of capital-

---

[27] These results differ from those that appeared in an earlier version of this paper which did not adjust for the cyclical variance common to country *i* and the United States. In the earlier version, there appeared to be significantly more convergence of both rates of growth and levels when PPPs rather than 1985 exchange rates were used. The differences were also less marked when 1980 market exchange rates were used for comparison.

Table 11.11 **Output Equations for Industrial Countries (using Catch-up Model for non-U.S. and Gross Private Capital Stocks)**

	LNQS	LNCQ	LNSGAP	LNIGAP	SEE	R^2	Durbin-Watson
USA	1.0000	−0.2084	0.7028	0.0117	0.0086	0.9979	0.7737
	(***)	(12.28)	(19.61)	(3.68)			
Japan	1.0000	−0.0897	0.7992	0.0117	0.0074	0.9996	0.8912
	(***)	(8.75)	(32.25)	(3.68)			
West Germany	1.0000	−0.1419	0.6466	0.0117	0.0099	0.9976	1.0331
	(***)	(6.61)	(24.35)	(3.68)			
France	1.0000	−0.2057	0.8342	0.0117	0.0107	0.9983	0.6568
	(***)	(14.13)	(27.28)	(3.68)			
United Kingdom	1.0000	0.0099	0.5031	0.0117	0.0216	0.9740	0.4584
	(***)	(0.43)	(8.29)	(3.68)			
Italy	1.0000	−0.0265	0.9024	0.0117	0.0144	0.9963	0.3011
	(***)	(2.00)	(29.82)	(3.68)			
Canada	1.0000	−0.3378	0.6715	0.0117	0.0106	0.9987	0.7494
	(***)	(11.72)	(23.25)	(3.68)			
Australia	1.0000	−0.1477	1.2043	0.0117	0.0126	0.9973	1.1462
	(***)	(10.32)	(19.89)	(3.68)			
Austria	1.0000	−0.1366	0.6344	0.0117	0.0101	0.9983	0.6602
	(***)	(4.64)	(33.08)	(3.68)			
Belgium	1.0000	−0.0890	0.6024	0.0117	0.0087	0.9986	1.0673
	(***)	(5.33)	(27.37)	(3.68)			
Denmark	1.0000	−0.1075	0.5047	0.0117	0.0097	0.9966	1.1054
	(***)	(9.14)	(20.31)	(3.68)			
Finland	1.0000	−0.0080	0.6335	0.0117	0.0131	0.9973	0.8066
	(***)	(0.49)	(18.52)	(3.68)			
Ireland	1.0000	0.0140	0.5640	0.0117	0.0286	0.9904	0.8584
	(***)	(0.32)	(9.75)	(3.68)			
Netherlands	1.0000	−0.0465	0.5035	0.0117	0.0106	0.9976	0.9078
	(***)	(2.63)	(29.18)	(3.68)			
New Zealand	1.0000	−0.0797	0.8839	0.0117	0.0156	0.9903	1.3699
	(***)	(5.52)	(27.96)	(3.68)			
Norway	1.0000	−0.0300	0.2698	0.0117	0.0181	0.9956	0.8053
	(***)	(0.73)	(5.65)	(3.68)			
Spain	1.0000	−0.0244	0.5422	0.0117	0.0126	0.9979	0.6621
	(***)	(1.24)	(10.06)	(3.68)			
Sweden	1.0000	−0.0352	0.5672	0.0117	0.0107	0.9959	1.6315
	(***)	(1.93)	(15.78)	(3.68)			
Switzerland	1.0000	−0.3771	0.5780	0.0117	0.0213	0.9766	0.5057
	(***)	(6.40)	(11.66)	(3.68)			

Note: Sample 1963–85. Estimation by Zellner's SUR estimation technique with instruments. See table 11.9 for variables abbreviated in cols. 1–4.

Table 11.12 **Output Equations for Industrial Countries (using Catch-up Model for non-U.S. and Gross Business Capital Stocks)**

	LNQS	LNCQ	LNSGAP	LNIGAP	SEE	R^2	Durbin-Watson
USA	1.0000	−0.2533	0.7146	0.0095	0.0077	0.9983	0.7630
	(***)	(13.69)	(22.22)	(3.14)			
Japan	1.0000	−0.0870	0.7929	0.0095	0.0075	0.9996	0.8607
	(***)	(8.06)	(31.33)	(3.14)			
West Germany	1.0000	−0.1968	0.6466	0.0095	0.0095	0.9978	1.0025
	(***)	(8.32)	(26.37)	(3.14)			
France	1.0000	−0.2709	0.8088	0.0095	0.0093	0.9987	0.7524
	(***)	(16.80)	(29.66)	(3.14)			
United Kingdom	1.0000	−0.0153	0.5621	0.0095	0.0216	0.9739	0.4108
	(***)	(0.48)	(9.62)	(3.14)			
Italy	1.0000	−0.0497	0.8901	0.0095	0.0144	0.9963	0.3009
	(***)	(2.76)	(30.37)	(3.14)			
Canada	1.0000	−0.4741	0.6222	0.0095	0.0095	0.9990	0.9017
	(***)	(11.80)	(20.49)	(3.14)			
Australia	1.0000	−0.1873	1.2047	0.0095	0.0125	0.9973	1.1369
	(***)	(11.07)	(20.99)	(3.14)			
Austria	1.0000	−0.1788	0.6327	0.0095	0.0097	0.9985	0.6969
	(***)	(5.76)	(32.97)	(3.14)			
Belgium	1.0000	−0.0965	0.6048	0.0095	0.0083	0.9987	1.1159
	(***)	(4.81)	(27.11)	(3.14)			
Denmark	1.0000	−0.1202	0.5222	0.0095	0.0095	0.9967	1.0200
	(***)	(8.07)	(21.66)	(3.14)			
Finland	1.0000	−0.0137	0.6412	0.0095	0.0130	0.9973	0.8083
	(***)	(0.63)	(18.94)	(3.14)			
Ireland	1.0000	−0.0187	0.6078	0.0095	0.0286	0.9904	0.8425
	(***)	(0.32)	(10.94)	(3.14)			
Netherlands	1.0000	−0.0275	0.4960	0.0095	0.0106	0.9977	0.9144
	(***)	(1.32)	(28.70)	(3.14)			
New Zealand	1.0000	−0.0881	0.8849	0.0095	0.0157	0.9902	1.3596
	(***)	(5.79)	(28.42)	(3.14)			
Norway	1.0000	−0.1595	0.3876	0.0095	0.0178	0.9957	0.7522
	(***)	(3.04)	(7.22)	(3.14)			
Spain	1.0000	−0.0354	0.5723	0.0095	0.0119	0.9982	0.7211
	(***)	(1.35)	(10.70)	(3.14)			
Sweden	1.0000	−0.0608	0.5887	0.0095	0.0106	0.9960	1.5886
	(***)	(2.91)	(17.86)	(3.14)			
Switzerland	1.0000	−0.4938	0.7025	0.0095	0.0196	0.9803	0.6585
	(***)	(9.12)	(14.30)	(3.14)			

Note: Sample 1963–85. Estimation by Zellner's SUR estimation technique with instruments. See table 11.9 for variables abbreviated in cols. 1–4.

Table 11.13 **Non-nested Tests of Catch-up Models**

(1) Catch-up Output Model, table 11.9 (total capital)
(2) Catch-up Output Model, table 11.11 (private capital)
(3) Catch-up Output Model, table 11.12 (business capital)

		Coefficient	*t*-Ratio
C Test of output equations:			
Test A:	Model (1)	−0.1482	0.26
	Model (2)	1.1482	2.03*
Test B:	Model (1)	−0.1840	0.81
	Model (3)	1.1840	5.22*
Test C:	Model (2)	−0.6609	2.06*
	Model (3)	1.6609	5.17*

	t-Ratio		*F*-statistic (H = 0.0)		
	H1	H2	H1, H2	H1	H2
P Test of output equations:					
H_0: Model (1), H_1 = Model (2), H_2 = Model (3)	3.92*	6.29*	22.10*	15.34*	39.63*
H_0: Model (2), H_1 = Model (1), H_2 = Model (3)	3.38*	6.24*	19.52*	11.42*	38.97*
H_0: Model (3), H_1 = Model (1), H_2 = Model (2)	3.41*	3.90*	7.89*	11.65*	15.22*

* = significance at the 95% level for the "t" test and rejection of the null hypothesis at 5% level for the "F" test.

embodiment effects.[28] Previous efforts using data for the G-7 industrial countries to look for linkages between gross investment and productivity growth have not been encouraging.[29] We now have comparable data for a much larger sample of countries, so we can try again. To provide a simple comparison between our base case and a capital-embodied vintage model, we compare our constant and convergence cases with an alternative model based on the assumption that all technical progress inheres in new fixed investment. We estimate the rate of such technical progress in just the same way as was done

---

[28] Baily emphasizes the reduction in capital services per measured unit of capital, because of increased obsolescence due to changes in energy prices and other changes in market opportunities and regulations. This implies that capital is not malleable ex post, and other things equal, that technical progress will be faster the higher the rate of gross investment, and hence the rate at which new techniques and current relative prices are embodied in the capital stock.

[29] Some earlier attempts to test for these effects using data for the G-7 countries revealed no apparent link between gross investment rates and the growth of the capital-adjusted productivity measure used in this paper. See Helliwell, Sturm, Jarrett, and Salou (1986, pp. 91–95). However, cross-sectional evidence reviewed by Englander and Mittelstadt (1988), covering seventeen countries, suggests that capital accumulation may have more impact on productivity growth than would be consistent with Harrod-neutral technical progress.

Table 11.14 **Non-nested Tests of Pure Catch-up Models (using alternative measures of gross capital stocks)**

(1) Catch-up Output Model, table 11.9 (total capital)
(2) Catch-up Output Model (total capital with inventory stock)
(3) Catch-up Output Model, table 11.11 (private capital)
(4) Catch-up Output Model (private capital with inventory stock)
(5) Catch-up Output Model, table 11.12 (business capital)
(6) Catch-up Output Model (business capital with inventory stock)

C Test of Output Equations

	(1)	(2)	(3)	(4)	(5)	(6)
(1)	—	1.8939	−0.1482	0.2942	−0.1840	−0.1809
		(1.48)	(0.26)	(.44)	(0.81)	(0.68)
(2)	−0.8939	—	−0.0766	0.0086	−0.1060	−0.1494
	(0.70)		(0.17)	(0.01)	(0.51)	(0.60)
(3)	1.4818	1.0766	—	2.2409	−0.6610	−0.6185
	(2.03)	(2.41)		(2.12)	(2.06)	(1.61)
(4)	0.7058	0.9914	−1.2409	—	−0.4671	−0.6633
	(1.06)	(1.62)	(1.18)		(1.70)	(1.87)
(5)	1.1840	1.1060	1.6610	1.4671	—	2.3429
	(5.22)	(5.35)	(5.18)	(5.36)		(3.25)
(6)	1.1809	1.1494	1.6185	1.6633	−1.3429	—
	(4.44)	(4.63)	(4.21)	(4.68)	(1.86)	

	F-statistic (H1 = H2 = H3 = H4 = H5 = 0.0)
P Test of output equations:	
HO: Model (1) (5,428df)	18.64 vs. 2.21
HO: Model (2) (5,428df)	19.05 vs. 2.21
HO: Model (3) (5,428df)	17.65 vs. 2.21
HO: Model (4) (5,428df)	18.38 vs. 2.21
HO: Model (5) (5,428df)	12.75 vs. 2.21
HO: Model (6) (5,428df)	14.26 vs. 2.21

in estimating the country-specific rates of Harrod-neutral technical progress in our constant case. Thus we calculate for each country the rate of investment-embodied technical progress that causes synthetic output from the production function to have the same rate of growth as actual output, averaged over the entire sample period. The estimated productivity equations for the capital-embodied model are reported in table 11.15.

When the derived output equations for the capital-embodied model (as shown in table 11.16) are compared with those of the basic convergence model (as reported in table 11.9), they show an overall preference for the convergence model, but there is an interesting pattern to the results. For ten European countries, including all of the original members of EEC, the convergence model is preferred, usually by a substantial margin. For the United States the two models have the same fit (there is, in any case, no convergence in the table 11.9 equation for the United States), and the comparisons are also rather close for New Zealand, Australia, Spain, and Sweden. For Norway and Japan, there is an apparent preference for the capital-embodiment hypothesis over the convergence hypothesis. In both countries, the largest growth of productivity was apparently linked to spurts of investment. For Norway, this is probably linked to the offshore oil developments, while for Japan it is more likely based on the addition of modern manufacturing capacity. By contrast, for the main EEC countries, the rapid growth of productivity appears to be more closely linked to the gradual integration of markets and less tied to variations in the rate of business investment.

The fact that the same pure vintage model of technical progress is for some countries preferred to the convergence model, and for most countries preferred to the model assuming Harrod-neutral technical progress at a constant rate, suggests that further research would be justified. In particular, it might be possible to generalize the capital embodiment hypothesis by adding some flexibility to the putty-clay assumption,[30] and to experiment with alternative ways of combining convergence with some degree of capital-embodiment.[31]

11.4. Modeling Business Cycles

Much recent analysis of business cycle fluctuations has made use of a neoclassical growth model with a production structure almost identical to that underlying the productivity analysis of this paper. Most of the real business cycle models surveyed by King, Plosser and Rebello (1988) use an aggregate Cobb-Douglas production function based on fixed capital and efficiency units of labor, with Harrod-neutral productivity growing at a constant expected annual rate. We also make use of the Harrod-neutral productivity assumption, and technical progress at a constant rate is one of the main alternatives we have assessed. In this section we attempt to compare the two approaches.

The main empirical applications of the real business cycle approach have involved the use of autocorrelated technology shocks to generate distributions

---

[30] For example, in Helliwell, Sturm, Jarrett, and Salou (1986), a putty/semi-putty model for energy/capital substitution was developed, wherein an estimated fraction of the existing capital stock was able to be retrofitted to employ the same optimal energy/capital ratio being built into new investment.

[31] Our tests of convergence models containing capital-embodiment effects have so far not produced strong embodiment results. The tests were done by adding the logarithm of the smoothed ratio of gross investment to gross domestic product, divided by the United States smoothed investment ratio to the basic catch-up model. When the embodiment variable was constrained to be the same across countries it had a positive (.0213) but insignificant coefficient ($t = 1.40$).

Table 11.15 **The Capital-Embodied Model of Technical Progress**

	RTIME	Constant	SEE	R^2	Durbin-Watson
United States	0.0194	126.8300	0.1116	0.6293	0.3312
	(6.64)	(596.31)			
Japan	0.1046	118.6800	0.2758	0.8899	0.1386
	(14.50)	(225.74)			
West Germany	0.0773	120.9800	0.1203	0.9587	0.2394
	(24.58)	(527.65)			
France	0.0982	119.4700	0.1845	0.9409	0.0882
	(20.34)	(339.70)			
Italy	0.0918	119.7900	0.2416	0.8903	0.1336
	(14.53)	(260.19)			
United Kingdom	0.0443	123.1300	0.0998	0.9172	0.5902
	(16.97)	(647.47)			
Canada	0.0515	123.7600	0.1200	0.9119	0.2163
	(16.40)	(541.22)			
Australia	0.0433	123.8900	0.1077	0.9008	0.4947
	(15.37)	(603.47)			
Austria	0.0881	119.7900	0.1586	0.9455	0.1340
	(21.24)	(396.32)			
Belgium	0.0833	120.8200	0.1212	0.9637	0.2402
	(26.29)	(523.24)			
Denmark	0.0627	121.7600	0.1298	0.9291	0.3083
	(18.46)	(491.97)			
Finland	0.0852	119.6100	0.1189	0.9666	0.3755
	(27.41)	(527.83)			
Ireland	0.0953	118.7100	0.1328	0.9666	0.5319
	(27.45)	(469.19)			
Netherlands	0.0786	121.6200	0.1322	0.9521	0.2594
	(22.74)	(482.57)			
New Zealand	0.0043	126.9800	0.1403	0.0506	0.4944
	(1.18)	(474.81)			
Norway	0.0662	121.6600	0.0759	0.9772	0.7040
	(33.37)	(841.30)			
Spain	0.1105	118.4000	0.1733	0.9581	0.2180
	(24.39)	(358.53)			
Sweden	0.0455	123.2300	0.1269	0.8787	0.3147
	(13.72)	(509.64)			
Switzerland	0.0432	124.1200	0.1449	0.8335	0.1889
	(11.41)	(449.39)			

Note: The dependent variable is ln π_m, measured output attributable to labor. RTIME is an annual time trend equal to 60 in 1960, 61 in 1961. See the section on specification in appendix B for a more complete description. Estimation was by Zellner's SUR estimation technique using sample 1960–85.

Table 11.16 Output Equations for Industrial Countries (capital-embodied technical progress)

	LNQS	LNCQ	LNSGAP	LNIGAP	SEE	R^2	Durbin-Watson
United States	1.0000	−0.1736	0.7176	0.0077	0.0085	0.9980	0.7876
	(***)	(13.58)	(24.23)	(1.95)			
Japan	1.0000	−0.1653	0.8621	0.0077	0.0070	0.9997	1.1251
	(***)	(14.50)	(49.82)	(1.95)			
Germany	1.0000	−0.3189	0.7525	0.0077	0.0199	0.9904	0.5244
	(***)	(12.45)	(15.37)	(1.95)			
France	1.0000	−0.2823	0.9381	0.0077	0.0145	0.9968	0.7504
	(***)	(15.84)	(23.12)	(1.95)			
Italy	1.0000	−0.0385	1.0526	0.0077	0.0154	0.9958	0.3175
	(***)	(2.67)	(36.77)	(1.95)			
United Kingdom	1.0000	−0.0577	0.5923	0.0077	0.0255	0.9636	0.2725
	(***)	(2.58)	(8.54)	(1.95)			
Canada	1.0000	−0.4089	0.6550	0.0077	0.0134	0.9979	0.7919
	(***)	(13.70)	(15.72)	(1.95)			
Australia	1.0000	−0.1142	1.3167	0.0077	0.0125	0.9973	1.3172
	(***)	(9.21)	(14.10)	(1.95)			
Austria	1.0000	−0.4514	0.6997	0.0077	0.0199	0.9935	0.5135
	(***)	(11.83)	(18.56)	(1.95)			
Belgium	1.0000	−0.2218	0.6346	0.0077	0.0119	0.9974	0.8781
	(***)	(16.44)	(22.80)	(1.95)			
Denmark	1.0000	−0.1299	0.6336	0.0077	0.0143	0.9927	0.7361
	(***)	(11.54)	(24.01)	(1.95)			
Finland	1.0000	−0.1014	0.6014	0.0077	0.0175	0.9951	0.4845
	(***)	(6.17)	(13.04)	(1.95)			
Ireland	1.0000	−0.1063	0.5865	0.0077	0.0309	0.9888	0.6745
	(***)	(2.82)	(8.66)	(1.95)			
Netherlands	1.0000	−0.2694	0.6173	0.0077	0.0230	0.9890	0.3747
	(***)	(10.18)	(20.35)	(1.95)			
New Zealand	1.0000	−0.0693	0.8537	0.0077	0.0152	0.9908	1.4148
	(***)	(5.27)	(22.06)	(1.95)			
Norway	1.0000	−0.1849	0.2579	0.0077	0.0150	0.9969	0.9998
	(***)	(5.94)	(5.46)	(1.95)			
Spain	1.0000	−0.1364	0.8391	0.0077	0.0131	0.9978	0.7713
	(***)	(8.14)	(21.81)	(1.95)			
Sweden	1.0000	−0.1329	0.5988	0.0077	0.0117	0.9952	1.2295
	(***)	(8.36)	(14.34)	(1.95)			
Switzerland	1.0000	−0.4773	0.6774	0.0077	0.0274	0.9614	0.4752
	(***)	(8.34)	(9.72)	(1.95)			

Note: Sample 1963–85. Estimation by Zellner's SUR estimation technique with instruments. See table 11.9 for variables abbreviated in cols. 1–4.

of key macroeconomic variables, with the aim of seeing to what extent these experimental distributions compare with those of actual data. Although it is theoretically possible to generate autocorrelated movements of output and investment in real business cycle models without autocorrelated technology shocks (e.g., Long and Plosser 1983), King, Plosser and Rebello show that if realistic assumptions are made about the longevity of capital it is necessary to have serially correlated technology shocks in order to generate realistic amounts of persistence in the simulated series for investment, output, and employment. The usual assumption made is that of first-order autocorrelation of the technology shocks,[32] and that is the form we shall consider here.

A modest generalization of the factor utilization model, using the constant technical progress assumption and adding some dynamic adjustment to the output equation, includes the output sector of the real business cycle model and the constant case of the factor utilization approach as nested special cases. This permits the encompassing principle (Mizon and Richard 1986) to be applied to see whether the general model can be reduced to either of the special cases without significant loss of information.

The generalization required is to add the lagged value of the utilization rate to the estimation of the output equation. Under the assumption of a serially correlated multiplicative technology shock, the previous period's factor utilization rate is the previous period's technology disturbance. It represents all the systematic information available, beyond the stocks of currently employed factors represented by the synthetic production function, to explain current output. If the production function with autocorrelated disturbances is a sufficient explanation of actual output, then the three additional variables reflecting current unexpected or temporary levels of demand, profitability, and inventories will add nothing to the explanation of current output. On the other hand, if the dynamics of the actual output decision are as specified in earlier sections, then the lagged dependent variable should not have a significant coefficient.[33]

Table 11.17 shows the results of estimating the more general hypothesis in the constant case, while table 11.18 shows the corresponding results for the catch-up case.[34] F-tests of the restricted hypotheses against the more general ones show that the restricted hypotheses are strongly rejected. This means that unexpected demand and cost conditions, with consequential changes in the rate of utilization of employed factors, are likely to be an important part of the cyclical movements in output, and that there are significant dynamics in

---

[32] E.g., Kydland and Prescott (1982) and Hansen (1985).

[33] Adding the lagged factor-utilization rate is equivalent to adding the lagged dependent variable under the maintained hypothesis that the log of synthetic output is constrained to have a unit coefficient in the equation for the log of output.

[34] In both cases, the inventory gap coefficient is constrained to have the same value for all countries.

the response of output to these changes that are not captured by the contemporaneous versions of the output equation tested earlier in this paper.

11.5. Conclusions

Over the period since 1960, data for nineteen industrial countries show significant evidence of international convergence in the rates of growth of labor efficiency. The evidence is much less strong for eventual convergence of the asymptotic levels of real output attributable to each worker. However, there remain many international differences in natural resources, education levels, and other factors that would justify continuing differences in measured productivity levels.

There is also significant evidence that technical progress has been faster, other things being equal, for countries that have been increasing their openness to international trade. The results also suggest that more work needs to be done to develop better data and theory to explain the linkages between technology transfer and openness to trade and capital movements.

We also found some evidence that capital embodiment may contribute more to productivity growth than our previous research had suggested. Although we found convergence to be more important than embodiment effects, both effects appear to help in explaining international differences in the levels and rates of growth of productivity. When the two were combined in a single model, however, the embodiment effects were not strong.

Our results in favor of the convergence hypothesis should be regarded as provisional, especially as they involve joint tests within a specific model of output determination. Caution is especially appropriate because the tests based on the derived factor demand equations, while being much weaker in their preference rankings, are also less supportive of the convergence models.

Turning to questions of data, we found that the use of the theoretically preferable PPP exchange rates tended to strengthen the convergence results. This was clear when the PPP results were compared to results based on the use of either 1980 or 1985 market exchange rates, which differed markedly from PPP rates for many country pairs.

We also found that narrower measures of the capital stock (business fixed capital) appeared to determine output more closely than broader measures that included housing and public capital. Further research may help to suggest whether this result is due to greater measurement problems with the stocks of housing and public capital, to problems in measuring and attributing the real output effects of these forms of capital, or to lower marginal returns on these forms of investment. Adding inventories to fixed capital in the synthetic production function tended to worsen the fit of the derived output equations.

Finally, the constant and convergence versions of the factor utilization models estimated in earlier sections were compared to the output sector frequently used in real business cycle models, with both being nested in a more general

Table 11.17 **Generalized Output Equation Incorporating Technology Shocks and Factor Utilization Variables (Using "Constant" Case)**

	LN(QS)	$LN(Q/QS)_{-1}$	LNCQ	LNSGAP	LNIGAP	SEE	R^2	Durbin-H
United States	1.0000	0.2471	−0.1522	0.5210	0.0196	0.0079	0.9982	1.9890
	(***)	(5.13)	(9.21)	(8.87)	(4.55)			
Japan	1.0000	−0.0074	−0.1511	0.8808	0.0196	0.0072	0.9997	2.3285
	(***)	(0.18)	(12.40)	(19.11)	(4.55)			
West Germany	1.0000	0.7266	−0.2343	0.2555	0.0196	0.0130	0.9959	0.2654
	(***)	(10.03)	(9.27)	(3.77)	(4.55)			
France	1.0000	0.8038	−0.1167	0.2347	0.0196	0.0079	0.9991	2.5554
	(***)	(9.48)	(5.98)	(2.47)	(4.55)			
United Kingdom	1.0000	0.7698	−0.1068	0.3923	0.0196	0.0144	0.9884	−0.0429
	(***)	(10.65)	(4.23)	(4.06)	(4.55)			
Italy	1.0000	0.5837	−0.0606	0.4462	0.0196	0.0105	0.9981	0.7422
	(***)	(8.03)	(3.56)	(5.22)	(4.55)			
Canada	1.0000	0.5290	−0.3584	0.2786	0.0196	0.0100	0.9988	0.3281
	(***)	(7.76)	(11.35)	(4.33)	(4.55)			
Australia	1.0000	0.2128	−0.1062	1.0129	0.0196	0.0108	0.9980	0.2040
	(***)	(3.66)	(7.44)	(11.94)	(4.55)			
Austria	1.0000	0.9196	−0.1905	0.0433	0.0196	0.0111	0.9980	−0.1522
	(***)	(14.31)	(5.72)	(0.79)	(4.55)			
Belgium	1.0000	0.4556	−0.1557	0.3642	0.0196	0.0103	0.9980	0.1764
	(***)	(5.93)	(8.09)	(7.03)	(4.55)			
Denmark	1.0000	0.7556	−0.0733	0.1683	0.0196	0.0140	0.9930	−1.0259
	(***)	(6.54)	(3.98)	(2.23)	(4.55)			

Finland	1.0000	0.5718	−0.0975	0.2984	0.0196	0.0129	0.9973	0.5412
	(***)	(7.50)	(4.88)	(4.55)	(4.55)			
Ireland	1.0000	0.8490	−0.1171	0.1464	0.0196	0.0227	0.9939	−0.2673
	(***)	(8.76)	(2.68)	(1.56)	(4.55)			
Netherlands	1.0000	0.8361	−0.1879	0.1886	0.0196	0.0129	0.9966	−0.3399
	(***)	(12.63)	(6.68)	(4.37)	(4.55)			
New Zealand	1.0000	0.3250	−0.0421	0.6681	0.0196	0.0134	0.9929	−0.8706
	(***)	(6.80)	(3.01)	(14.96)	(4.55)			
Norway	1.0000	0.4643	−0.1589	0.2360	0.0196	0.0124	0.9979	0.1516
	(***)	(6.43)	(5.37)	(4.93)	(4.55)			
Spain	1.0000	0.5897	−0.1119	0.3537	0.0196	0.0107	0.9985	0.0262
	(***)	(6.17)	(5.52)	(4.23)	(4.55)			
Sweden	1.0000	0.3787	−0.1097	0.3601	0.0196	0.0109	0.9958	0.1932
	(***)	(4.19)	(5.59)	(4.85)	(4.55)			
Switzerland	1.0000	0.7067	−0.2539	0.2775	0.0196	0.0107	0.9940	−0.0310
	(***)	(17.55)	(7.61)	(7.07)	(4.55)			

Note: Sample 1963–85. Estimation by Zellner's SUR estimation technique with instruments. See table 11.9 for variables abbreviated in cols. 1 and 3–5. LN (Q/QS)$_{-1}$ is the logarithm of the lagged utilization rate, which is defined as the ratio of actual to normal output.

Nested Tests:	*Wald Statistic (19df):*
LN(Q/QS)$_{-1}$ = 0.0	1457.4678 vs. 28.87
LNCQ = 0.0	835.3252 vs. 28.87
LNSGAP = 0.0	1229.7174 vs. 28.87
LNIGAP = 0.0	309.2629 vs. 28.87
LNCQ = LNSGAP = LNIGAP = 0.0	4970.1135 (57df) vs. 79.08

Table 11.18 Generalized Output Equation Incorporating Technology Shocks and Factor Utilization Variables (Using "Catch-up" Case)

	LN(QS)	LN(Q/QS)$_{-1}$	LNCQ	LNSGAP	LNIGAP	SEE	R^2	Durbin-H
United States	1.0000	0.2176	−0.1723	0.5691	0.0370	0.0078	0.9983	2.4005
	(***)	(4.21)	(10.02)	(8.81)	(9.82)			
Japan	1.0000	−0.1969	−0.0761	0.9572	0.0370	0.0076	0.9996	2.7124
	(***)	(3.83)	(6.75)	(21.00)	(9.82)			
West Germany	1.0000	0.2016	−0.1231	0.5495	0.0370	0.0095	0.9978	1.5421
	(***)	(2.72)	(5.74)	(10.70)	(9.82)			
France	1.0000	0.7960	−0.1257	0.4200	0.0370	0.0089	0.9988	3.1372
	(***)	(9.39)	(6.76)	(6.31)	(9.82)			
United Kingdom	1.0000	0.7213	−0.1002	0.3731	0.0370	0.0150	0.9874	0.7018
	(***)	(7.70)	(3.36)	(5.31)	(9.82)			
Italy	1.0000	0.5101	−0.0167	0.5920	0.0370	0.0101	0.9982	1.5232
	(***)	(7.78)	(1.02)	(10.52)	(9.82)			
Canada	1.0000	0.3697	−0.2907	0.4113	0.0370	0.0092	0.9990	1.3954
	(***)	(4.64)	(8.33)	(6.39)	(9.82)			
Australia	1.0000	0.2292	−0.1139	0.9748	0.0370	0.0111	0.9979	0.6887
	(***)	(3.32)	(6.68)	(11.56)	(9.82)			
Austria	1.0000	0.3159	−0.0443	0.4619	0.0370	0.0086	0.9988	1.7442
	(***)	(3.53)	(1.23)	(7.95)	(9.82)			
Belgium	1.0000	0.2200	−0.0683	0.4857	0.0370	0.0085	0.9986	1.0639
	(***)	(2.84)	(3.21)	(10.94)	(9.82)			
Denmark	1.0000	0.3813	−0.0726	0.3406	0.0370	0.0100	0.9964	0.0416
	(***)	(3.38)	(4.91)	(5.82)	(9.82)			

Finland	1.0000	0.2852	−0.0136	0.5327	0.0370	0.0112	0.9980	2.0879
	(***)	(4.64)	(0.84)	(11.43)	(9.82)			
Ireland	1.0000	0.7067	−0.0527	0.2598	0.0370	0.0220	0.9943	−0.2679
	(***)	(7.54)	(1.09)	(3.36)	(9.82)			
Netherlands	1.0000	0.3147	−0.0748	0.3834	0.0370	0.0097	0.9981	1.0165
	(***)	(4.93)	(3.47)	(11.01)	(9.82)			
New Zealand	1.0000	0.3602	−0.0515	0.6630	0.0370	0.0133	0.9931	−1.1015
	(***)	(6.61)	(3.26)	(12.44)	(9.82)			
Norway	1.0000	0.5333	−0.1049	0.2803	0.0370	0.0131	0.9977	0.4263
	(***)	(7.09)	(3.23)	(5.55)	(9.82)			
Spain	1.0000	0.5197	−0.0075	0.3693	0.0370	0.0103	0.9986	0.2635
	(***)	(5.33)	(0.25)	(3.90)	(9.82)			
Sweden	1.0000	0.2235	−0.0093	0.4482	0.0370	0.0104	0.9961	0.1744
	(***)	(2.52)	(0.47)	(6.78)	(9.82)			
Switzerland	1.0000	0.7019	−0.1740	0.2994	0.0370	0.0106	0.9942	0.3035
	(***)	(14.45)	(4.49)	(7.95)	(9.82)			

Note: Sample 1963–85. Estimation by Zellner's SUR estimation technique with instruments. See table 11.9 for variables abbreviated in cols. 1 and 3–5. LN (Q/QS)$_{-1}$ is the logarithm of the lagged utilization rate, which is defined as the ratio of actual to normal output.

Nested Tests:	*Wald Statistic (19df):*
LN(Q/QS)$_{-1}$ = 0.0	758.8765 vs. 28.87
LNCQ = 0.0	327.6833 vs. 28.87
LNSGAP = 0.0	1790.4562 vs. 28.87
LNIGAP = 0.0	289.0660 vs. 28.87
LNCQ = LNSGAP = LNIGAP = 0.0	2840.5842 (57df) vs. 79.08

model. The tests showed significant evidence that the more general model, including the demand and profitability effects of the factor utilization model, and the dynamics of the technology shock model, was to be preferred over either of the more restricted alternatives.[35]

Overall, the importance of the openness effects and the potential importance of capital-embodiment effects support the emphasis in the theoretical literature (Romer 1986, Grossman and Helpman 1989a) on the idea that the rates of generation and diffusion of technical progress are endogenous rather than exogenous variables, and are hence potentially affected by a variety of domestic and international policies.

A final general conclusion, supporting the focus on international data issues, is that the use of comparable data for a substantial number of countries has permitted far stronger tests and results than would be available from the analysis of time-series data for one or even several countries.

Appendix A
Data Sources

List of Variables and Parameters

Variables	Description
a	Real absorption, billion 1980 currency
c	Real personal consumption expenditures, billion 1980 currency
e_r	Exchange rate, U.S. dollar per domestic currency
g	Real government current and capital expenditures on goods and services, billion 1980 currency
i	Real total fixed investment, billion 1980 currency
ib	Real business fixed investment, billion 1980 currency
ip	Real private fixed investment, billion 1980 currency
i_{inv}	Real value of physical change in inventories, billion 1980 currency
k	Real total gross fixed capital stock, billion 1980 currency
kb	Real business gross fixed capital stock, billion 1980 currency
kp	Real private gross fixed capital stock, billion 1980 currency
k_{inv}	Real stock of inventories, billion 1980 currency
m	Real imports of goods and services, billion 1980 currency
N	Total employment, millions of persons

---

[35] This is in line with the real business cycle research agenda proposed by Plosser (1989, pp. 70–71), who emphasized the need to study the source characteristics of the "technology shocks" and to undertake systematic comparisons of alternative approaches.

N_{pop}	Total population of labor force age, millions of persons
p_a	Implicit price of absorption, 1980 = 1.0
p_{gdp}	GDP deflator, defined as ratio of nominal GDP to real GDP
p_k	Price of capital services
p_m	Price of imported goods and services, 1980 = 1.0
p_q	Implicit price for gross domestic output, 1980 = 1.0
p_x	Price of exports of goods and services, 1980 = 1.0
q	Real gross output (at factor cost), billion 1980 currency
q_s	Real synthetic supply, billion 1980 currency
r	Average interest rate, annual percent
r_l	Average yield on government bonds, 10 years and over, percent
r_s	Average yield on government bonds, 1–3 years, percent
t	Time: 1960 = 1, 1961 = 2, etc.
T_i	Total indirect taxes less subsidies, billion currency
W	Wage rate, thousands of dollars per year per employed person
x	Real exports of goods and services, billion 1980 currency
y	Real gross national product, billion 1980 currency
δ_2	Scrapping rate for capital stock (including housing)
Π	Labor productivity index for Harrod-neutral technical progress in CES function for q
ρ_r	Estimated parameter; real supply price of capital
τ	Estimated parameter; elasticity of substitution between labor and capital in the CES function
μ	Estimated parameter; distribution parameter in the CES function
ν	Estimated parameter; distribution parameter in the CES function

Note: Units exceptions to those specified above are for Japan and Italy. Currency data for these two are in trillions, demographic data are in billions, while wages remain in thousands.

Data Sources

Data for this study were taken from: IMF International Financial Statistics; OECD, *Flows and Stocks of Fixed Capital*, 1960–85; OECD Standardized National Accounts (SNA), vols. 1 and 2; OECD 1984, 1986, and 1987 INTERLINK supply block tapes for G7 countries; and OECD 1987 INTERLINK supply block tape for the smaller OECD countries.

Most of the supply block data for this study can be derived from the OECD Standardized National Accounts (SNA) as indicated below. Square brackets indicate source and data mnemonic. Note that $ is used to denote domestic currency. Sample period: 1960–85.

YGDP = GDP in current $ billion [SNA GDP]
PGDP = GDP deflator (1980 = 1.00) [SNA GDPE/GDPEV]
I = Private, housing, and government investment in 1980 $ billion [SNA GF]
IB = Business investment = I − IG − IH
IG = Government investment [SNA vol. 2 and OECD87 for smalls]
IH = Housing investment [SNA vol. 2 and OECD87 for smalls]
IP = Private investment = I − IG
A = Absorption in 1980 $ billion [SNA PC + GF + GC]
PA = Absorption deflator (1980 = 1.00) [SNA A/(PCV + GFV + GCV)]
C = Private consumption in 1980 $ billion [SNA PC]
G = Government expenditures in 1980 $ billion [SNA GC]
IINV = Change in inventories in 1980 $ billion [SNA STV]
TI = Indirect taxes less subsidies in current $ billion [SNA ITX − SUB]
N = Total employment, million of persons [OECD86, OECD87 ET]
W = Average annual wage (thousands of $ per employed person per year) [OECD86, OECD87 (WSSE × EE + CGW)/(EG + EE)]
X = Exports of goods and services in 1980 $ billion [SNA EXPV]
PX = Price of exports (1980 = 1.00) [SNA EXP/EXPV]
ER = Exchange rate [IFS]
RS = Short-term nominal interest rate [Canadian Dept. of Finance and IFS 60]
RL = Average yield of long-term government bonds (%) [Canadian Dept. of Finance and IFS 61]
R = Average interest rate = $.5RS + .5(RL_{-1} + RL_{-2} + RL_{-3})/100/3$
XIY = Total investment income receipts from abroad in current $ billion [SNA FIFW]
MIY = Total investment income payments to foreigners in current $ billion [SNA FITW]
M = Imports of goods and services in 1980 $ billion [SNA IMPV]
PM = Price of imports (1980 = 1.00) [SNA IMP/IMPV]
NPOP = Total population (millions of persons) [IFS and SNA]
RSCR = Scrapping rate [OECD84 RSCRB and OECD87 for smalls]
KS = Kick-off value for capital stock in 1980 $ billion (see below)
KINVS = Kick-off value for inventory levels in 1980 $ billion [for G7 OECD86 inventory stock, for smalls an aproximation of .06K (1960) was used]
Q = (YGDP − TI)/PGDP Real gross output
Y = YGDP/PGDP + XIY/PGDP − MIY/PGDP Real gross national product

The wage and employment data for both the G7 and small countries were derived from INTERLINK supply block data supplied by OECD.

Capital Stock Series

For the G-7 countries, *total* capital stocks were generated from base (1959) kick-off values (KS). For each year, the previous year's stock was added to new investment after allowing for some portion, which is scrapped off, i.e., $K_t = (1 - \mathrm{RSCR})k_{t-1} + I$. The KS data were taken from the OECD84 tape for the G-7 countries, and it is the kick-off value for the total gross stock series. In the case of Japan, however, data were available only from 1966; some extrapolation was done to get the 1960 total capital stock as the kick-off value. *Business* capital stocks were the KBV series from the OECD86 tape, rebased to 1980 $ where applicable. For Japan, data were available only from 1966; extrapolating backwards using the formula $\mathrm{KBV}_t = (1 - \mathrm{RSCRB})\mathrm{KBV}_{t-1} + \mathrm{IBV}$ (RSCRB is business scrapping rate; IBV is business investment), the business capital stock was estimated for 1960–65. A business scrapping rate of 4.15% per year was assumed for the 1960–65 period, to approximate the rate of 4.197% in 1966, the first year when data were available. In the case of France, the business capital stock series was built up using a kick-off value of 2138.2 billion francs in 1960 and RSCRB from the OECD86 tape. This kick-off value is obtained from OECD, *Flows and Stocks of Fixed Capital*. *Private* capital stocks were generated the same way as total capital stocks, using a base (1960) kick-off value and business scrapping rate. As no data are readily available on private capital stocks, the kick-off stock is estimated based on the assumption that the 1960–69 average ratio of private investment to business investment applies to the stock ratio. For example, for the United States private investment was 165% of business investment in the 1960s. This ratio was applied to business capital stock of $2,251.6 billion in 1960 to get $3,722.2 billion as the kick-off value for private capital stock.

For the 12 smaller industrial countries, *business* capital stock data were readily available from the OECD87 supply block tape, with those for Austria, New Zealand, and Switzerland having to be rebased to 1980 $.

The OECD87 tape has data on government, business, and housing investments. These data were compared with corresponding data available from OECD SNA, vol. 2 and were updated and revised where necessary. The private investment series was then generated as the sum of business and housing investments (IPV = IBV + IHV). From this, the 1960s average ratio of private investment to business investment was applied to the stock ratio to derive the kick-off private capital stock in 1960, as in the case of the G-7 countries. The *private* capital stock series was then generated for each of the 12 smaller industrial countries, using the business scrapping rate to approximate the scrapping rate for private capital stock. (The RSCRB data were available from the OECD87 tape. For some countries, however, estimates had to be made for the earlier years, particularly 1960 and 1961.) In the same way, a government capital stock series was generated, which was then added to private capital stock to get the *total* capital stock series.

The inventory stock series was calculated using the equation KINV = KINV_{-1} + IINV, with KINVS being the base kick-off value.

The 1980 GDP PPPs are obtained from the OECD *Annual National Accounts: Main Aggregates* computer tape (July 1988). They are available for the full sample of 19 countries examined in this paper. The values used are: United States 1.00; Japan 258.51; Canada 1.149; France 5.941; Germany 2.702; Italy 866.974; United Kingdom 0.517; Australia 1.042; Austria 16.626; Belgium 42.918; Denmark 8.517; Finland 5.022; Ireland 0.543; Netherlands 2.734; New Zealand 1.004; Norway 7.334; Spain 70.554; Sweden 6.888; Switzerland 2.449.

Table 11A.1 **The Ratio of Market Exchange Rates to GDP PPPs**

Country	1980	1985
United States	1.0000	1.0000
Japan	0.8771	1.0745
Canada	1.0176	1.1192
France	0.7113	1.2359
Germany	0.6727	1.1871
Italy	0.9879	1.4665
United Kingdom	0.8323	1.3719
Australia	0.8426	1.1548
Austria	0.7782	1.2464
Belgium	0.6814	1.3314
Denmark	0.6617	1.0812
Finland	0.7427	1.0382
Ireland	0.8969	1.3084
Netherlands	0.7271	1.3024
New Zealand	1.0229	1.4985
Norway	0.6734	0.9962
Spain	1.0162	1.7843
Sweden	0.6141	1.0557
Switzerland	0.6844	1.0166

Note: Market exchange rates are defined as domestic currency per U.S. dollar.

Table 11A.2 **Capital/Output and GDP Per Capita Ratios (1960 and 1985)**

Year	Capital/Output Ratios (beginning and end of sample values)					GDP Per Capita (beginning and end of sample values)				
	United States	*Japan*	*Canada*	*France*	*Germany*	*United States*	*Japan*	*Canada*	*France*	*Germany*
1960	3.0347	1.8840	4,1617	4.7568	3.5406	7.7728	2.3098	5.7863	4.1558	4.8670
1985	3.3563	3.9681	4.2062	4.2766	4.8882	13.0052	9.2956	11.9753	8.9332	9.5511
	Italy	*United Kingdom*	*Australia*	*Austria*	*Belgium*	*Italy*	*United Kingdom*	*Australia*	*Austria*	*Belgium*
1960	3.7849	4.0276	3.2818	3.1809	3.3049	3.3202	5.3185	5.3650	3.7339	3.9490
1985	4.1174	5.2576	3.9660	4.4477	3.7283	7.1607	8.6127	9.8141	8.5101	8.4698
	Denmark	*Finland*	*Ireland*	*Netherlands*	*New Zealand*	*Denmark*	*Finland*	*Ireland*	*Netherlands*	*New Zealand*
1960	5.4335	4.6195	3.9028	3.6609	2.3222	4.9574	3.8243	2.5642	4.9125	5.6987
1985	4.0901	5.2453	4.9717	4.3095	3.4696	9.6846	9.0761	5.3365	8.9070	7.9725
	Norway	*Spain*	*Sweden*	*Switzerland*		*Norway*	*Spain*	*Sweden*	*Switzerland*	
1960	5.0479	3.3856	4.0842	3.9432		4.5277	2.4085	5.3356	7.2253	
1985	5.0939	4.2115	4.6309	4.3347		11.0457	5.9864	9.9783	11.3867	

Table 11A.3 **Average Labor Share of GDP**

Country	Average Share	Minimum	Maximum
United States	0.7919	0.5954	0.8957
Japan	0.7778	0.5232	0.9465
Germany	0.8060	0.6479	0.9140
France	0.8407	0.5952	0.9270
United Kingdom	0.8615	0.6339	0.9629
Italy	0.8970	0.6434	0.9749
Canada	0.8296	0.6253	0.9113
Australia	0.7841	0.4587	0.9241
Austria	0.8261	0.6485	0.9286
Belgium	0.8200	0.6282	0.9157
Denmark	0.8713	0.7268	0.9472
Finland	0.8856	0.7123	0.9677
Ireland	0.9173	0.7338	0.9809
Netherlands	0.8140	0.6472	0.9271
New Zealand	0.7781	0.2943	0.9446
Norway	0.8339	0.6347	0.9275
Spain	0.8741	0.5674	0.9748
Sweden	0.8463	0.6205	0.9432
Switzerland	0.7550	0.5805	0.8747

Note: Average share of labor is defined as the sample average of $gdp - p_k k)/gdp$, 1960–85.

Table 11A.4 **Supply Price of Capital (Pr)**

United States	7.0515	Canada	5.1707
Germany	4.6756	United Kingdom	4.1680
Austria	5.5411	Denmark	3.7215
Ireland	1.9759	New Zealand	11.4984
Spain	4.7292	Switzerland	6.7305
Japan	8.1297	France	3.8872
Italy	2.3127	Australia	8.5177
Belgium	6.4483	Finland	2.4184
Netherlands	6.0547	Norway	3.7659
Sweden	4.4788		

Appendix B
Specification

Modeling Labor Productivity

The CES two-factor production function which defines normal output q_s is:

$$\text{(B1)} \qquad q_s = [\mu(\Pi N)^{(\tau-1)/\tau} + \nu k^{(\tau-1)/\tau}]^{\tau/(\tau-1)}.$$

The following will first discuss the procedure used to derive expression for the country-specific parameters ν, μ, and Π. The final values of these parameters depend on the value of τ, the elasticity of substitution between labor and capital, which is determined iteratively. The iteration method used to calculate τ will be examined last.

(B1) can be rewritten by setting $q=q_s$ and by isolating the following expression for Π:

$$\text{(B2)} \qquad \Pi = [\,(q^{(\tau-1)/\tau} - \nu k^{(\tau-1)/\tau})/(\mu N^{(\tau-1)/\tau}]^{\tau/(\tau-1)}.$$

(B2) is used to obtain an expression for the parameter ν. First the optimum factor ratio is derived. The partial derivatives of (B1) with respect to labor and capital are calculated and set equal to the prices W and p_k. Assuming the factor ratio is optimal provides the following ratio:

$$\text{(B3)} \qquad \Pi N^*/k^* = (p_k\Pi/w)^{\tau}(\mu/\nu)^{\tau}$$

where the price of capital services is:

$$p_k = (<\delta_2> + 0.01\ \rho_r)p_a,$$

and where

$$\rho_r = 100<1 - (WN + <\delta_2>\bar{k}p_a)/(qp_q)>/<(\bar{k}p_a)/(qp_q)>,$$

so that the ratio of factor costs to revenues is unity, on average (as $\langle x\rangle$ denotes the sample average of x).

(B2) is substituted into (B3). The parameter μ drops out and can be determined empirically when Π is normalized, as shown below. The parameter ν is isolated in the substituted equation and sample averages are taken to provide the following expression:

$$\text{(B4)} \qquad \nu=<(p_k/W)(q/N)^{(\tau-1)/\tau}>/[<(N/k)^{1/\tau}> + <(p_k/W)(k/N)^{(\tau-1)/\tau}>].$$

Note that we normalize so that the sample average of the ratio of the factors raised to the $1/\tau$ power is equal to the average for optimum proportions.

The value of Π, the labor productivity index for Harrod-neutral technical progress, is derived by the following procedure. Output attributable to labor is defined by rewriting (B2):

$$\text{(B5)} \qquad \mu\Pi^{(\tau-1)/\tau} = (q^{(\tau-1)/\tau} - \nu k^{(\tau-1)/\tau})/N^{(\tau-1)/\tau}.$$

In the constant growth model, the technical progress index is modeled to grow at a constant rate. The model is estimated by ordinary least squares by regressing the logarithm of the measured efficiency level, which is the logarithm of the value provided by (B5), referred to as ln π_{mi}, for country i, on an annual time index. Given the final value of τ, the fitted values ln π_i, can be estimated for each year. Using the latter, the value of μ is calculated by setting $\Pi_i = 1.0$ in 1980. Given that the value of μ is constant throughout the sample period, the labor efficiency index Π_i is defined simply as the exponent of ln $\hat{\pi}_i$ minus 1980 ln $\hat{\pi}_i$, which ensures it has a value of 1 in 1980.

In the second model, the growth of technical progress in the non-U.S. countries is assumed to converge to the U.S. rate of growth. This is modeled by regressing ln (π_{mi}/π_{mus}), where π_{mi} is the measured productivity index for country i and π_{mus} is the measured value for the U.S., on ln (π_{mus}/π_{mi-1}), with the coefficient on the lagged dependent variable constrained to equal 1.0 on the right-hand side of the equation. The fitted values ln $\hat{\pi}_i$ are then calculated by multiplying the estimated regression parameters by the right-hand side variables (the exception being the measured U.S. index, which is replaced by the smoothed U.S. constant trend series $\hat{\pi}_{us}$). The series $\hat{\pi}_i$ is then used to derive the noncyclical technical progress index Π_i, as was done for the constant case. In the third model, in order to allow for the effects of globalization on the model, we include the variable DOPENA along with the catch-up variables in the non-U.S. equations. DOPENA is the annual change in "openness," defined as the log difference of current and lagged values of the five-year moving average of exports plus imports divided by GNP. The values of the CES parameters are derived in a similar way to the constant case, using the fitted values of the catch-up case, ln $\hat{\pi}_i$. The fourth model tests the "break" hypothesis. The technical progress index is modeled with a constant time index, but includes an additional index starting in 1974. If the latter index is negative, there is some evidence for the hypothesis that there was general reduction in the underlying rate of productivity growth starting in 1974. The last model assumes declining growth and is modeled by regressing π_{mi} on a declining trend which straightforwardly replaces the single time trend for the constant case. The declining trend takes on values such that if the step from the first period to the second is 1.0, then the step from the next-to-last to the last period is only 0.7 (i.e., the rate of growth has declined by 30% over the 25-year sample).

Finally, an estimate of τ is needed to derive final values of the above parameters. The iterative procedure uses the expression for the optimum factor ratio, (B3). The log of this equation provides the following form that can be estimated:

$$\text{(B6)} \qquad \ln(\Pi N^*/k^*) = \tau \ln(\mu/\nu) + \tau \ln(p_k\Pi/W).$$

The coefficient of the inverse price ratio is τ. An arbitrary value of τ is used to define μ, ν, Π. (B6) is then estimated by ordinary least squares, and the estimated coefficient provides a new value of τ, which is used to redefine the other parameters in the next round. The process is repeated until the value of τ in (B6) converges. This value is used to obtain the final values of μ, ν, Π, and normal output, q_s. For our final estimates, a variant of (B6) was used in which the lagged capital-labor ratio was included along with cyclical demand and profitability variables (outlined in Helliwell and Chung 1986) as right-hand-side variables. The latter were included since the factor-share ratio has, in addition to its responsiveness to relative prices, a cyclical variance caused by the fact that labor adjusts more quickly than the capital stock to changes in desired output. The distributed lag response on the relative price term (which tends to produce a higher estimated equilibrium elasticity of substitution) also provides more reasonable elasticities across countries.

In the pooled estimation, we use an average of the country-specific τ and ν (with value of .99 for τ), thus providing common production function parameters. The econometric technique used to estimate the productivity equations is Zellner's seemingly unrelated regression technique, since there is significant evidence of cross-country correlation of the error terms. The systems of equations are estimated with the generalized least squares procedure, although the iterative procedure for the covariance matrix of residuals across equations is not used.

Output Investment and Employment

The following provides a brief description of the specification of the equations used in the non-nested tests reported in the tables.

The Output Equation

We follow the "factor utilization" approach outlined in Helliwell and Chung (1986). The rationale for explicitly modeling factor utilization rates lies in the observation that factors of production are quasi-fixed. That is, it is costly for firms to adjust the levels of inputs in response to short-run changes in demand and cost conditions. Consequently, temporary fluctuations in demand are met by varying the intensity of factor use—working the inputs harder or not as hard—or, in other words, by changing the factor utilization rates.

One difficulty with this approach is that factor utilization rates are not directly observable. In particular, we have no idea what constitutes a "normal" factor utilization rate. A simple way around the problem is to define the utilization rate as the ratio of actual to normal output and to form suitable proxies for the demand and cost conditions. When the proxy variables are at their normal values—the sample averages—then we have a normal rate of factor utilization.

The output equation thus has the following specification:

$$\text{(B7)}\quad \ln q = \ln q_s + \beta \ln sgap + \beta_1 \ln cq + \beta_2 \ln igap + e$$

where *sgap* is the ratio of sales to normal sales, *igap* is the ratio of desired to lagged actual inventories, and *cq* is the ratio of current unit cost relative to output price (an inverse measure of profitability). Normal sales is defined as $<s/q_s> \times q_s$, and desired inventories is $<kinv - 1/q_s>q_s$, where *kinv* is inventory stock. The sample averages ensure that the means of *sgap*, *igap*, and *cq* are 1, which ensures "normal" utilization rates on average.

The Investment Equation

The equation explains fixed investment as a fraction of the corresponding capital stock, with the lagged ratio entering the equation to enrich the distributed lag response. Driving the investment equation is the gap between desired and the actual capital stock $(k^* - k)/k$. The desired k^* is derived as follows. First, define a level of output (q^*) which is the expected desired output for firms. We define $q^* = q_a\ (q/q - 2)$, where q_a is aggregate demand (output minus unintended change in inventories). The time horizon implicit in q^* is thus two years. Given our CES production function, the level of desired output is used in the long-run production function to determine the levels of capital and labor that would minimize costs if future relative prices were the same as those currently prevailing. Analytic expressions for k^* and N^* are thus easily obtained:

$$k^* = [\nu + \mu^{\tau}\,(\Pi p_k/w\nu)^{\tau-1}]^{\tau/(1-\tau)}q^* \tag{B8}$$

and

$$N^* = (1/\Pi)[(q^{*(\tau-1)/\tau} - \nu \overset{*}{k}{}^{(\tau-1)/\tau})/\mu]^{\tau/(\tau-1)} \tag{B9}$$

Lastly we include *cq*. This attempts to capture financial market conditions by defining profitability as the ratio of current unit operating costs to the current output price, where the numerator includes a rental charge of capital, which varies with the long-term nominal interest rate.

The Employment Equation

The employment equation describes a partial adjustment to the two-year forward-looking demand for labor (N^*). The employment equation follows a simple adaptive adjustment, with right-hand side variables, lagged and desired employment levels, constrained to sum to one.

References

Abramovitz, M. 1986. Catching up, Forging Ahead, and Falling Behind. *Journal of Economic History* 46:385–406.

Baily, M. N. 1981. Productivity and the Services of Capital and Labor. *Brookings Papers on Economic Activity* 1:1–50.

Barro, R. J. 1978. Unanticipated Money, Output and the Price Level in the United States. *Journal of Political Economy* 86:549–80.

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

Baumol, W. J., and E. N. Wolff. 1988. Productivity Growth, Convergence and Welfare: Reply. *American Economic Review* 78:1155–59.

Blades, D., and D. Roberts. 1987. A Note on the New OECD Benchmark Purchasing Power Parities for 1985. *OECD Economic Studies* 9:153–84.

Bruno, M., and J. Sachs. 1985. *Economics of Worldwide Stagflation.* Cambridge, Mass.: Harvard University Press.

Chenery, H., S. Robinson, and M. Syrquin. 1986. *Industrialization and Growth: A Comparative Study.* Washington, D.C.: Oxford University Press for the World Bank.

Davidson, R., and J. G. MacKinnon. 1981. Several Tests for Model Specification in the Presence of Alternative Hypotheses. *Econometrica* 49:781–94.

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

Dollar, D., and E. Wolff. 1988. Convergence of Industry Labor Productivity among Advanced Economies, 1963–1982. *Review of Economics and Statistics* 70:549–58.

Englander, S., and A. Mittelstadt. 1988. Total Factor Productivity: Macroeconomic and Structural Aspects of the Slowdown. *OECD Economic Studies* 10:7–56.

Godfrey, L. G. 1983. Testing Non-nested Models after Estimation by Instrumental Variables or Least Squares. *Econometrica* 51:355–65.

Gordon, R. J., and M. Baily. 1989. Measurement Issues and the Productivity Slowdown in Five Major Industrial Countries. Paper presented at International Seminar on Science, Technology, and Economic Growth. June 6. Paris.

Greenwood, J., Z. Hercowitz, and G. W. Huffman. 1988. Investment, Capacity Utilization and the Real Business Cycle. *American Economic Review* 78:402–17.

Grossman, G. M., and E. Helpman. 1989a. Endogenous Product Cycles. NBER Working Paper no. 2913.

———. 1989b. Growth and Welfare in a Small Open Economy. NBER Working Paper no. 2970.

Hansen, G. D. 1985. Indivisible Labor and the Business Cycle. *Journal of Monetary Economics* 16:309–27.

Helliwell, J. F. 1986. Supply-side Macroeconomics. *Canadian Journal of Economics* 19:597–625.

Helliwell, J. F., and A. Chung. 1986. Aggregate Output with Variable Rates of Utilization of Employed Factors. *Journal of Econometrics* 33:285–310.

———. 1988. Aggregate Productivity and Growth in an International Comparative Setting. Paper prepared for the U.S. SSRC conference on International Productivity and Competitiveness. October. Stanford University, Palo Alto, California.

Helliwell, J. F., P. H. Sturm, P. Jarrett, and G. Salou. 1986. The Supply Side in the OECD's Macroeconomic Model. *OECD Economic Studies* 6:75–131.

Helliwell, J. F., P. H. Sturm, and G. Salou. 1985. International Comparison of the Sources of Productivity Slowdown, 1973–1982. *European Economic Review* 28:157–91.

Heston, A., and R. Summers. 1988. What Have We Learned about Prices and Quantities from International Comparisons: 1987. *American Economic Review* 78, no. 2:467–73.

Hill, T. P. 1986. International Price Levels and Purchasing Power Parities. *OECD Economic Studies* 6:133–59.

King, R. G., C. I. Plosser, and S. T. Rebello. 1988. Production, Growth and Business Cycles. *Journal of Monetary Economics* 21:195–232, 309–41.

Kravis, I. B., A. Heston, and R. Summers 1978. *The United Nations International Comparison Project: Phase II, International Comparisons of Real Product and Purchasing Power.* Baltimore: Johns Hopkins University.

Kravis, I. B., and R. E. Lipsey. 1984. The Diffusion of Economic Growth in the World Economy, 1950–80. In *International Comparisons of Productivity and Causes of the Slowdown*, ed. J. W. Kendrick. Cambridge: Ballinger.

———. 1989. The International Comparison Program: Current Status and Problems. Paper prepared for conference on International Economic Transactions. November. Washington, D.C.

Kydland, F., and E. Prescott. 1982. Time to Build and Aggregate Fluctuations. *Econometrica* 50:1345–70.

Lindbeck, A. 1983. The Recent Slowdown of Productivity Growth. *Economic Journal* 93:13–34.

Long, J. B., and C. I. Plosser. 1983. Real Business Cycles. *Journal of Political Economy* 91:39–69.

Lucas, R. E. 1973. Some International Evidence on Output-Inflation Tradeoffs. *American Economic Review* 63:326–34.

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

———. 1987. Growth and Slowdown in Advanced Capitalist Economies: Techniques of Quantitative Measurement. *Journal of Economic Literature* 25:649–98.

Mizon, G. E., and J.-F. Richard. 1986. The Encompassing Principle and its Application to Non-Nested Hypotheses. *Econometrica* 54:657–78.

Nordhaus, W. D. 1982. Economic Policy in the Face of Declining Productivity Growth. *European Economic Review* 18:131–57.

Ohkawa, O., and H. Rosovsky. 1973. *Japanese Economic Growth: Trend Acceleration in the Twentieth Century.* Stanford.

Plosser, C. I. 1989. Understanding Real Business Cycles. *Journal of Economic Perspectives* 3:51–78.

Psacharopoulos, G. 1984. The Contribution of Education to Economic Growth: International Comparisons. In *International Comparisons of Productivity and Causes of the Slowdown*, ed. J. W. Kendrick. Cambridge: Ballinger.

Rauch, J. E. 1989. The Question of International Convergence of Per Capita Consumption: An Euler Equation Approach. NBER Summer Institute Paper (August).

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

Rostow, W. W. 1978. *The World Economy: History and Prospect.* Austin: University of Texas Press.

Solow, R. M. 1957. Technical Change and the Aggregate Production Function. *Review of Economics and Statistics* 39:312–20.