NBER WORKING PAPER SERIES

TRADE AND TECHNICAL PROGRESS

John F. Helliwell

Working Paper No. 4226

NATIONAL BUREAU OF ECONOMIC RESEARCH
1050 Massachusetts Avenue
Cambridge, MA 02138
December 1992

I am grateful for the research support of the Humanities and Social Science Research Council of Canada, and for extensive advice from Alan Chung, who worked with me on much of the earlier research on which this paper is based. An earlier version of the paper was presented at the International Economic Association conference on Economic Growth and the Structure of Long-Term Development, Lake Como, October 1-3, 1992. In revising this paper, I have made use of many helpful suggestions from conference participants, especially Dan Ben-David, Rob Feenstra, Elhanan Helpman, Maurice Scott, and Robert Solow. This paper is part of NBER's research program in International Trade and Investment. Any opinions expressed are those of the author and not those of the National Bureau of Economic Research.

NBER Working Paper #4226
December 1992

TRADE AND TECHNICAL PROGRESS

ABSTRACT

Using annual data 1963-1989 for technical progress in OECD countries (as measured by Solow residuals constructed using OECD data made internationally comparable through the use of purchasing power parties), the paper first shows that there has been significant international convergence in the rates of technical progress, with the initially poorer countries having faster technical progress. Country effects are found to be more significant than year effects, so subsequent analysis of the effects of trade on the growth of technology are done using 27 annual cross-sections of 19 countries each, with cross-equation restrictions applied and tested. The results suggest that both the level data and rate of increase in trade intensity lead to more rapid technical progress, with some additional effect from country size. Finally, there appears to be no evidence that countries with higher investment rates have had faster rates of technical progress, once the capital-deepening effects of investment have been taken into account via the production function used to define the Solow residuals.

John F. Helliwell
Center for International Affairs
Room 403B
Harvard University
1737 Cambridge Street
Cambridge, MA 02138
and NBER

I INTRODUCTION

This paper is focussed on two important questions in the comparative study of economic growth. First, do all countries share the same production possibilities? More specifically, has the apparent convergence in per capita income growth among the industrial countries[1] been made possible by higher investment rates in the initially poorer countries, as would be implied by a neoclassical growth model with uniform technology available to all countries, or is technical progress faster in the initially poorer countries? Second, if there is evidence of convergence in the growth rates of technical progress, to what extent does the rate of convergence depend upon trade flows and other measures of openness? For both questions, the main results will make use of data for 19 industrial countries covering the period from 1963 to 1989.

The first question sets the stage for the second, because evidence of international knowledge transfers increases the likelihood that some aspects of openness are important to growth, as international transfers of knowledge would seem to presuppose some degree of openness[2]. Evidence that convergence takes time would also pose the need for a theoretical framework within which technology transfers require time and resources to implement.

The next section sets out the framework for analysis and presents the evidence of linked international differences on the levels and rates of change of technical efficiency, while the following section goes on to consider the links between trade and technical progress. Evidence is found linking trade and technical progress, with some additional contribution from country size but none from the investment rate.

II ARE THERE INTERNATIONAL DIFFERENCES IN RATES OF TECHNICAL PROGRESS?

Many studies of comparative growth make use of a neoclassical production function, often of Cobb-Douglas form with constant returns to scale, thus assuming that the same technological possibilities are available in each country. Under these circumstances, international differences in per capita income levels must be due to differences in capital/labour ratios (or to unmeasured differences in factor quantities and qualities), and differences in growth rates are based on initial disequilibria which are being removed by higher investment rates in the poorer countries. Viewed in this context, findings of convergence in growth rates of per capita incomes (Mankiw, Romer and Weil, 1990; Barro 1991) are regarded as evidence of initial deviations from steady state growth paths, and are seen to be supportive of the underlying assumption that equivalent technologies are available in all countries.

Some recent studies of economic growth have noted that universal access to the same technologies would imply very high rates of return to investment in the poorest countries, and much greater capital inflows to those countries than are in fact observed (Lucas 1990). Others have thought that observed convergence is too low or too slow to support the basic neoclassical model, and have invoked some version of economies of scale at the national level (Romer 1986) to explain continuing or possibly increasing international differences in per capita incomes. These growth externalities are sometimes seen to relate to the scale of R&D, to the scale of manufacturing, to the concentration of manufacturing activities, to the size of the stock of human capital, to the size of the stock of physical capital, or to the size of GDP. Although many of these frameworks are described as endogenous growth models, it is probably more accurate to refer to them as models of endogenous technical progress, since they are primarily alternative ways of determining the rate of growth of what in the simplest models is an exogenous index of technical progress.

Although much discussion has centered on the simplest neoclassical models (with Cobb-Douglas form, constant returns, and the same constant rate of technological progress in each country) and models of endogenous technical progress based on increasing returns at the national level, there are many alternatives available, since several elements of the neoclassical production function could differ among countries. There are many ways to model endogenous technical change without invoking increasing returns to scale, and various kinds of beneficial spillovers of the general sort appealed to in endogenous growth models can lead to convergence of per capita incomes (Tamura 1991).

The first order of business in this section is to review some direct evidence about the plausibility of assuming that the same production functions and efficiency levels are available in all countries. In one of the earliest cross-country studies of production structure, Arrow, Chenery, Minhas and Solow (1961) used a CES form to test whether a common production structure could be assumed for all countries. They found reasonably strong support for similar substitution and scale elasticities, but strong rejection of the assumption of similar levels of technical efficiency. They also found evidence of similar efficiency levels in different industries in the same country. The latter finding, which has subsequently been affirmed by other studies (Dossi, Pavitt and Soete 1990, p. 63), provides some rationale for using aggregate data, since if most or all industries in a country differ in the same way from those in other countries, then economy-wide influences are likely to be in play, and international differences in aggregate efficiency are not likely to be due to differing industry mixes.

To be both simple and concrete, consider the simplest form of neoclassical production function with real output in country (i) determined as a constant-returns Cobb-Douglas function of physical capital and efficiency units of labour:

$$Y_{i,t} = K_{i,t}^{\alpha}(A_{i,t}L_{i,t})^{1-\alpha} \qquad (1)$$

where L is the level of employment (growing at rate n), K is the stock of physical capital and A is the level of technology. To test whether this measure of technology has the same properties for each country, the assumed production function can be inverted, given a value for the share parameter α, to give a log-linear measured series of what are often referred to as Solow residuals, since this procedure for defining a series for technical change was first used in Solow (1957):

$$\ln A_{i,t} = (1/(1-\alpha))\ln Y_{i,t} - (\alpha/(1-\alpha))\ln K_{i,t} - \ln L_{i,t} \tag{2}$$

International and intertemporal differences in the series for $A_{i,t}$ will be due to a broad range of influences, including available stocks of land and natural resources, hours worked per year, the education and skills of employed workers, and the efficiency of national institutions and infrastructure. To make these series internationally comparable, the series for real GDP and aggregate gross capital stocks are converted into international dollars at purchasing power parities (Hill 1986, Blades and Roberts 1987), using 1960 to 1989 OECD data for 19 OECD countries[3]. An analysis-of-variance test applied to the means of the calculated $\ln A_{i,t}$ series for each of the 19 countries produces an F-value of 33.6 (compared to a 1% significance test value of 2.6), indicating no possibility that the technology level had the same average value in each country. A similar analysis of variance test applied to the first differences of the $\ln A_{i,t}$ series gives an F-value of 4.13, (vs 2.6 at 1%), also showing a very low likelihood that the technology indexes have the same rates of growth in each country.

Since the levels and rates of growth of the technology indexes apparently differ significantly among countries, the next task is to see if the growth rates show convergence patterns similar to those reported in many other studies for rates of growth of per capita incomes. This part of the research is in the spirit of recent theoretical growth studies (Grossman and Helpman 1991a, Romer 1990) treating technology as a tradeable economic commodity. However, the focus of this paper remains on the aggregate production structure, and the implications of trade flows for technology flows, without consideration of the underlying market or policy structures that influence international technology transfers. Earlier studies have shown U.S. efficiency levels to be the empirically preferred target for convergence[4], so that is the formulation used for the current experiments. The variables to be explained, by the use of time series and cross section data for 19 OECD countries from 1963 to 1989, are the synthetic technology measures defined by inverting a CES production function based on real GDP, total gross capital stocks and total employment. The general convergence formulation to be tested is:

$$\mathrm{dlnA}_{i,t} = \beta_{0i,t} + \beta_1 \ln(A_{1,t-1}/A_{i,t-1}) + \beta_2 \mathrm{dlnA}_{i,t-1} + \beta_j C_j + u_{i,t} \qquad (3)$$

where $\mathrm{dlnA}_{i,t}$ is the change from the last year to the current year in the calculated measure of technology for country (i) (and $\mathrm{dlnA}_{i,t-1}$ its lagged value), $(A_{1,t}/A_{i,t-1})$ is the ratio of the current level of efficiency in the United States to the preceding year's efficiency level in country i (referred to subsequently as the technology gap), the C_j are cyclical variables used in some experiments to test for cyclical sensitivity[5] of the other parameter estimates, and the $u_{i,t}$ are disturbance terms which are suspected to be cross-sectionally correlated. The constant terms $\beta_{0i,t}$ are included to allow for country or year effects in different specifications. The lagged value of the change in technical progress is included in the general formulation to test the assumption often made in real business cycle models (King, Plosser and Rebelo, 1988) that technology is subject to autocorrelated shocks. If all countries share the same production possibilities and the same patterns of exogenous shocks to technology, then

β_0 and β_2 should have the same values for all countries, and β_1 should be zero.

The initial estimations, for which test results are reported in Table 1, use Zellner's SUR estimator for a system of 19 equations with 27 annual observations for each country, covering the period from 1963 through 1989. The results confirm earlier experiments (Helliwell and Chung, 1991, Table 11.10), in revealing strong evidence for convergence of rates of technical progress[6], but also show that the rates of convergence are not the same for each country[7], and that there are very significant international differences in the constant terms β_{0i}.

Since the data do not accept that any of the parameters in equation (3) can be pooled across countries, and since the primary questions at issue relate to explaining the differences among countries, the emphasis in the remainder of this paper will be on the use of the data transposed to give 27 annual cross sections, each comprising 19 country observations[8]. In this form, there are separate constant terms for each year. This set of equations provides the test bed for the experiments in the next section that attempt to find the empirical linkages between trade and technical progress.

III TRADE AND GROWTH

Most studies of empirical linkages between trade and growth, which have been summarized and augmented by Harrison (1991), attempt to find linkages between measures of trade policy and per capita economic growth. For these purposes, measures of trade flows are often inadequate, since trade flows are determined by country size, factor endowments (Leamer 1988) and other variables not related to trade policies. For our current purposes, however, we have already identified patterns of international convergence of technical progress, and are interested in seeing whether international transfers of technology appear to be related to trade flows and other measures of openness. If trade intensity does affect the rate at which technology flows among countries, it probably does not matter whether the trade intensity is induced by differences in factor endowments, proximity, cultural ties or trade policies. To provide some test of this supposition, equations will be made using pure measures of trade intensity, and alternatively using residuals from equations explaining trade intensity. The principal measure used for trade intensity is the logarithm of the ratio of the sum of real imports and exports to GDP. One set of residuals will be those from a pooled time-series cross-sectional explanation of trade intensity ($TI = \ln(X + M/GDP)$) in terms of log real GDP and time:

$$TI = \underset{(47.65)}{.2533} + \underset{(174.45)}{.0338TIME} - \underset{(422.99)}{.3011\ln GDP_{i,t}} + R_{i,t} \tag{4}$$

where the $R_{i,t}$ are the estimated residuals, and the figures in parentheses are absolute values of t-statistics. Equation (4) was estimated by Zellner SUR, using 1962 through 1989 data for each of 19 OECD country equations, with all coefficients constrained to be the same in each country[9]. Since the general model to be estimated will already include both time (through the use of separate constant terms for each annual cross-section) and real GDP, as a scale variable, the estimated effects of openness will be equivalent whether the total or residual measures are used for trade intensity. The other residuals employed are those estimated by Leamer (1988, Table 6.8, overall scaled results) from regressions for trade/GNP ratios based on resources and distance.

The linkages among country size, openness and technical progress are complicated. Many models of endogenous growth assume domestic spillovers of knowledge, but no international transfers of the sort under study in this paper. In these models, country scale would increase growth because of scale effects. However, apparent scale effects could arise in a more symmetric global setup. Consider a world with equally spaced economic activity, with the intensity of both trade and knowledge flows decreasing as distance increases, and with some countries starting out at much higher efficiency levels. Assume also that national boundaries have no influence on the geographical patterns of trade and knowledge flows. Then suppose that arbitrary national boundaries are drawn, functionless except for the purposes of gathering GDP and trade statistics. Each country comprises contiguous territory, more like the United States than Chile in general shape, but countries are of different sizes. The national statistics would show lower foreign trade intensities for the larger countries, but countries would differ in their rates of technical progress only to the extent that their geographic areas started out at different levels of technology. Now suppose that national boundaries do mark cleavages in economic space, either because of restrictions that they frequently imply for the mobility of goods, services and especially population, or because the national boundaries may coincide with linguistic and cultural cleavages that themselves limit the rate at which knowledge is transferred around the globe. In this context, technical progress might be faster in the larger countries since their residents are presumed to have access to a larger domestic pool of knowledge. For given country size, larger trade flows might be a good proxy for the freer flows of ideas, on the presumption that whatever pattern of access and opportunities gave rise to the trade flows would also apply to knowledge transfers. This is over-simplified reasoning, but it may provide a sensible starting point.

If so, it would seem that any theory that permits a role for trade intensity as a proxy for factors likely to induce knowledge transfers ought also to include country size. Thus the equation form tested in this section is:

$$dlnA_{i,t} = \beta_{0t} + \beta_1 ln(A_{1,t-1}/A_{i,t-1}) + \beta_2 dlnA_{i,t-1} + \beta_3 TI_{i,t} + \beta_4 lnGDP_{i,t} + u_{i,t} \quad (5)$$

where TI is the measure of trade intensity and GDP is country size measured in international dollars converted at PPP exchange rates. As written, equation (5) restricts the coefficients to take the same value for each country and year, with the exception of the constant terms.

Table 2 reports the coefficients estimated for this form, and also shows chi-square tests of the restrictions. There continues to be very strong evidence in favour of convergence, and there is now much less evidence that the convergence coefficient changes from equation to equation. However, there is still only about a 5% chance that the convergence effects are the same for each of the 27 years. The estimated rate of technological convergence is, at .041, only about half as large as in the time series estimates.

The trade intensity and scale effects are both significant, with the latter significant in all years[10], and the former in almost all years. The probability of a zero value for either effect is very low. The trade share measure of trade intensity is more significant than the Leamer measure, but this may be in part because the Leamer series, which is based entirely on 1982 data, is not a relevant measure for the early years of the sample. Imposing equal scale and trade coefficients in each year is acceptable with less than 2% probability, imposing slope equality for all years in all variables is less likely still[11]. For the purposes of Figures 1 and 2 showing the effects of the various factors influencing technical progress in the industrial countries, the equation is restricted even more, with β_2 set equal to zero, and the dynamics thereby forced entirely into the annual constant terms, which thus show the year-to-year changes in measured technical progress that are not explained by convergence, scale and openness.

Figure 1 shows the year-to-year changes in the average of the annual logarithmic changes in technical progress in 19 OECD countries, along with the components separately attributable to convergence and to post-1963 increases in average openness and average scale in the 19 countries. The line labelled 'residual' is the plot of the separate annual constant terms from an equation containing post-1963 increases in scale and in openness, using equation (5) with the coefficients on the lagged dependent variable constrained to equal zero.

Figure 2 shows cumulated total technical progress, along with the components separately attributable to scale, convergence and openness. The residual component is shown separately where its cumulant is positive, and is elsewhere represented as that part of the convergence effect below zero on the y-axis. Technical progress cumulated to 60% for the typical OECD country over the 1963 to 1989 period, with the largest proportion attributable to convergence effects. Post-1963 increases in average scale and average openness each contributed about 10% to the 1989 technology level in OECD countries, while the residuals represented by the constant terms are very close to zero for the 1960s and early 1970s, and become negative thereafter, cumulating to a 20% loss of productivity by the end of the 1980s. Overall, if a successful model of technical progress is one that reduces the variance of the residual to zero, the results shown in Figures 1 and 2 cannot be considered a roaring success, even with respect to the contributions of openness and scale, since the figures show the cumulative contributions of scale and openness to be continuing to build up during the 1980s, accompanied by continued negative accumulation of residual effects.

The combination of fairly significant rejection of parameter homogeneity restrictions, and the still-large cumulation of unexplained residual effects suggests some further specification tests with the number of annual samples limited to the years from 1981 through 1989. This increases the likelihood that parameters estimated may be of relevance into the 1990s, and also permits the full application of the Zellner SUR estimation procedure, since the number of countries will then be greater than the number of years.

Another advantage of restricting the estimation to the 1980s, as is done for the results shown in Table 3, is that the Leamer index, based on 1982 data, is likely to be more comparable with other measures of openness. Table 3 shows that when the equations for the 1980s are pooled, the Leamer index is as strong as the trade share variable, which keeps about the same size coefficient as for the 27-year set of equations. A third measure of trade intensity is added, equal to the lagged change in trade shares. As Romer (1990), Harrison (1991) and others have noted, increased openness would be expected to increase measured efficiency levels through the achievement of gains from trade even if openness had no effect on transfers of knowledge. Given that imports plus exports have increased, as a share of GDP, by more than 3% per year over the 1963 through 1989 sample period (as revealed by the parameter estimates reported in equation (3)), then we would expect to see resulting increases in productive efficiency even if there were no continuing effects of openness on growth once trade intensity ceased to increase. Of course, it is possible that the increasing openness of the past thirty years has had both level and rate-of-growth effects, although it may be expecting too much to be able to separate them.

Case (1) of Table 3 shows the 1980s results using the level of trade intensity, and hence corresponds to the results reported at the bottom of Table

2 for the 1963-1989 period. Case (3) uses the first difference of the same openness measure, thus implying an equilibrium level relation between the degree of openness and the efficiency level. The level of trade intensity appears stronger than the first difference, judging from the t-statistics on the trade variables, and both appear inferior to the Leamer measure. Four further tests might help to settle the issue. First, as in case (4), it is possible to consider both effects simultaneously. The results show some evidence of both effects, with TI still seeming to contribute more than dTI in terms of explanatory power. Second, it is reasonable to see whether one formulation is better than the other in reducing the unexplained year-to-year variance implied by the freely estimated annual constant terms, as shown by cases (5) and (6). These results favour dTI over TI fairly strongly, as dTI now takes a more significant coefficient and gives an unexplained residual that is half as large on average over the 1980s, as revealed by the relative sizes of the constrained constant terms in the two equations.

Third, since both variables appear to have separate importance, and to have different effects in diminishing the variance of the annual constant terms, case (7) includes both variables, as was done in case (4), and constrains the constant terms to have the same values in each year. The results show both variables to be significant, with dTI the more significant of the two. Fourth, now that the trade intensity variable is potentially entering in two ways, there is a chance that the residuals from equation (3) may be preferable to the unadjusted measures of trade intensity. This is tested by case (8), in which case (7) is repeated using the levels and first differences of the equation (3) residuals as the measures of trade intensity. These results are rather similar to those in the preceding case. Overall, the experiments in Table 3 suggest that the level of openness may have effects on both the level and the rate of growth of productivity. If confirmed[12], this in turn suggests that some part of the observed positive linkage between openness and growth may relate to gains from expanding trade rather than to international knowledge transfers.

In the introduction, a contrast was made between growth frameworks that emphasize international convergence of technical progress and those that take convergence to be due mainly to higher or more effective investment in the faster-growing economies. To the extent that such a distinction is valid, the evidence from the Solow residuals favours the former approach. However, if technical progress is embodied in, or correlated with, the rate of investment, then the results would be less clear. To see whether there are strong embodiment or learning-by-investing effects, a four-year average rate of gross investment was added to equation (5), with coefficients estimated separately for each year. Of the freely estimated investment effects, two-thirds are negative, and only two of the 27 are significant at the 5%, one positive and one negative, about what would be expected if the true effect were randomly distributed about a zero mean. Hence it is reasonable to infer that the unexplained part of technical progress is not driven by capital embodiment or learning-by-investing effects.

IV CONCLUSIONS

This paper started by asking whether industrial countries can be taken to have shared similar production possibilities and technological progress over the past thirty years. Based on the properties of Solow residuals covering 19 OECD countries over 27 years, the answer was clear and explicit. There is strong evidence that rates of technical progress have differed among countries and from decade to decade, with the initially poorer countries having faster subsequent rates of technical progress. This provides strong encouragement for theoretical and empirical growth models that emphasize, as advocated by Pasinetti (1981, p. 250) international transfers of technology as the most important part of the international growth linkages.

Since country effects were found to be more significant than year effects, subsequent analysis of the effects of trade on technology growth were done using sets of annual cross-section, with cross-equation restrictions applied and tested. The results suggest that both the level and the rates of growth of trade intensity have led to more rapid technical progress, with some additional effect from country size. Finally, there appeared to be no evidence that countries with higher investment rates have had faster rates of technical progress.

The results linking trade with technological convergence are consistent with those of Ben-David (1992), who finds that reduced trade barriers tend to be associated with faster subsequent growth of per capita incomes. The results are not completely comparable, however, since his study explains per capita output growth, while this paper deals with efficiency growth. In addition, he concentrates on the consequences of reductions in trade barriers, while this paper considers increasing trade as a conduit of technological transfers, without consideration of the sources of increased openness. It thus remains to be discovered whether policy-induced increases in trade are more or less influential than those arising for other reasons. In either case, the potential leverage for policies to influence these linkages in such a way as to increase future efficiency growth cannot be easily assessed until the theoretical groundwork and empirical support are more solidly established.

REFERENCES

Abramovitz, M. (1990) 'The Catch-up Factor in Postwar Economic Growth', Economic Inquiry: 1-18.

Arrow, K.J., H.B. Chenery, B.S. Minhas and R.M. Solow (1961) 'Capital-Labor Substitution and Economic Efficiency', Review of Economics and Statistics 43: 225-250.

Backus, D.K., P.J. Kehoe and T.J. Kehoe (1991) 'In Search of Scale Effects in Trade and Growth', Working Paper No. 451 (Minneapolis, Federal Reserve Bank).

Barro, R.J. (1991) 'Economic Growth in a Cross Section of Countries', Quarterly Journal of Economics 106:407-44.

Ben-David, D. (1992) 'Income Disparity among Countries and the Effects of Freer Trade', Paper prepared for the IEA Conference on Economic Growth and the Structure of Long-Term Development, Lake Como, October 1992.

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

De Long, J.B. and L.H. Summers (1991) 'Equipment Investment and Economic Growth', Quarterly Journal of Economics 106:445-502.

Dollar, D., E.N. Wolff, and W.J. Baumol (1988) 'The Factor-Price Equalization Model and Industry Labor Productivity: An Empirical Test Across Countries', in R.C. Feenstra, ed., Empirical Methods for International Trade (Cambridge: MIT Press)

Dossi G., K. Pavitt and L. Soete (1990) The Economics of Technical Change and International Trade (Hemel Hempstead: Harvester Wheatsheaf).

Dowrick, S. and D-T. Nguyen (1989) 'OECD Comparative Economic Growth 1950-85: Catch-Up and Convergence', American Economic Review 79: 1010-30.

Dowrick, S. and N. Gemmell (1991) 'Industrialisation, Catching Up and Economic Growth: A Comparative Study Across the World's Capitalist

Economies', Economic Journal 101:263-275.

Easterly, W., M. Kremer, L. Pritchett and L.H. Summers (1992) 'Good Policy or Good Luck? Country Growth Performance and Temporary Shocks', (Washington: World Bank)

Grossman, G.M. and E. Helpman (1991a) Innovation and Growth in the Global Economy (Cambridge: MIT Press).

Grossman, G.M. and E. Helpman (1991b) 'Quality Ladders and Product Cycles', Quarterly Journal of Economics 106: 557-586.

Grossman, G.M. and E. Helpman (1991c) 'Endogenous Product Cycles', Economic Journal 101:

Harrison, A. (1991) 'Openness and Growth: A Time-Series, Cross-Country Analysis for Developing Countries', Policy Research Working Paper WPS809. (Washington: World Bank).

Helliwell, John F. (1992) 'International Growth Linkages: Evidence From Asia and the OECD', Prepared for the Third Annual NBER East Asian Seminar on Economics, Sapporo, Japan, June 17-19, 1992.

Helliwell, John F., and Alan Chung (1986) 'Aggregate Output with Variable Rates of Utilization of Employed Factors', Journal of Econometrics 19: 597-625.

Helliwell, John F., and Alan Chung (1991) 'Macroeconomic Convergence: International Transmission of Growth and Technical Progress', In P. Hooper and J.D. Richardson, eds., International Economic Transactions:

Issues in Measurement and Empirical Research (Chicago: University of Chicago Press) 388-436.

Helliwell, John F. and Alan Chung (1992) 'Tri-polar Growth and Real Exchange Rates: How Much Can be Explained by Convergence?' In L.R. Klein, C. Moriguchi and A. Amano, eds., A Quest for a More Stable World Economic System (New York: Kluwer).

Hill, P. (1986) 'International Price Levels and Purchasing Power Parities', OECD Economic Studies 6: 133-59.

King, R.G., C.I. Plosser, and S.T. Rebelo (1988) 'Production, Growth and Business Cycles', Journal of Monetary Economics 21: 195-232, 309-341.

Leamer, E.E. (1988) 'Measures of Openness', in R.E. Baldwin, ed., Trade Policy Issues and Empirical Analysis (Chicago: University of Chicago Press).

Linnemann, H. (1966) An Econometric Study of International Trade Flows (Amsterdam: North-Holland).

Lucas R.E. (1990) 'Why Doesn't Capital Flow from Rich to Poor Countries?' American Economic Review 90 (2): 92-96.

Mankiw, G., D. Romer and D. Weil (1990) 'A Contribution to the Empirics of Economic Growth', NBER Working Paper No. 3541 (Cambridge: National Bureau of Economic Research).

Pasinetti, L.L. (1981) Structural Change and Economic Growth (Cambridge: Cambridge University Press).

Rivera-Batiz, L.A. and P. Romer (1991) 'Economic Integration and Endogenous Growth', Quarterly Journal of Economics 106:531-56.

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

Romer, P.M. (1990) 'Endogenous Technological Change', Journal of Political Economy 98: S71-S102.

Solow, R.M. (1957) 'Technical Change and the Aggregate Production Function', Review of Economics and Statistics 39: 312-20.

Stokey, N.L. (1991) 'Human Capital, Product Quality, and Growth', Quarterly Journal of Economics 106:587-616.

Summers, R. and A. Heston (1988) 'A New Set of International Comparisons of Real Product and Prices: Estimates for 130 Countries, 1950 to 1985', Review of Income and Wealth 34: 1-25.

Summers, R. and A. Heston (1991) 'The Penn World Table (Mark 5): An Expanded Set of International Comparisons, 1950-1988', Quarterly Journal of Economics 106: 327-368.

Tamura, R. (1991) 'Income Convergence in an Endogenous Growth Model', Journal of Political Economy 99: 522-40.

Young, A.W. 'Learning by Doing and the Effects of Trade', Quarterly Journal of Economics 106: 369-405.

NOTES

1. For recent surveys of additions to the evidence, see Abramovitz (1990), Dowrick and Nguyen (1989), and Helliwell and Chung (1991). Making specific allowances for differences in human capital has permitted convergence to appear in global samples (Barro 1991, Mankiw, Romer and Weil 1991, Dowrick and Gemmell 1991) using the Summers and Heston (1988, 1991) data sets, but still is little support for convergence among the Asian economies, while there is evidence linking openness and growth in Asia (Helliwell 1992).

2. Recent theoretical papers imply very different linkages between openness and growth, depending on the particular assumptions about markets, endowments and technologies. For example, the linkage is positive in Ravira-Batiz and Romer (1991) and Grossman and Helpman (1991c), negative in Stokey (1991) and Young (1991) and ambiguous in Grossman and Helpman (1991b). For helpful surveys, see Helpman (1991) and Grossman and Helpman (1991a).

3. A CES rather than Cobb-Douglas functional form is used for the calculations reported in this paper, with parameters estimated following the procedures described in Helliwell and Chung (1991). The average estimated elasticity of substitution (.99) is so close to the 1.0 value implicit in the Cobb-Douglas form that nothing of consequence depends on the use of the CES

form, so the exposition here is in terms of the simpler Cobb-Douglas form that is in more frequent use in the theoretical literature. Rob Feenstra has noted that some related work has made use of Divisia or other quantity indexes in preference to either the Cobb-Douglas or CES forms. To see whether the choice of production function form is influencing the results, I calculated alternative productivity series using a Divisia quantity index for capital and labour as the measure of factor inputs. The logarithmic first differences of the Divisia residuals are very highly correlated with those of the Solow residuals used in equation (3). For every country the correlation between the two series exceeds .985 and for 15 of the 19 countries it exceeds .995. The results reported in the tables are thus uninfluenced by the choice of form for the production function. If the production function contained more than two factors, the choice of functional form might well start to play a more important role.

4. Experiments in a tri-polar context, with the United States, Germany (or some combination of leading European economies) and Japan as potential convergence targets in the three regions, (Helliwell and Chung 1992) showed the United States to be the empirically stronger convergence target for Asia, Canada and the major European economies, with the smaller European economies favouring a combination of the United States and the major European economies. Preliminary attempts to define a global frontier

empirically preferable to the United Sates were not successful.

5. The cyclical variables used are the first differences of the abnormal sales, profitability and inventory disequilibrium variables used in Helliwell and Chung (1986, 1991).

6. In the equations without cyclical variables, the convergence coefficients are positive for all 19 countries. Their t-values average 3.56, and are above 2.0 for all but four countries. With cyclical variables included, the convergence coefficients are significantly positive ($t > 2.0$) for all but two countries (being insignificantly negative in one of these two cases, New Zealand), and their average t-value is 4.56.

7. The tests in Table 1 show that there is less than one chance in twenty thousand that the coefficients are the same in each country. The convergence coefficients average .0978 (standard deviation=.060) without the use of cyclical variables, with a standard deviation of .06, falling to .0771 (SD=.061) with the addition of cyclical variables.

8. The tests using the full sample of 27 equations with 19 observations are estimated by OLS with cross-equation restrictions. The full Zellner procedure allowing for cross-equation covariance cannot be applied, since it requires more observations for each equation than there are equations being jointly estimated. Some of the results in the next section will split the sample into three sequential sets with nine annual cross sections in each set, thus

permitting the full SUR procedure to be applied.

9. Maurice Scott has suggested to me, following Linnemann (1966), that population might be better than aggregate GDP as a measure of the ability of local markets to substitute for foreign trade. Since equation (4) is nested within a more general form with both population and GDP per capita as variables explaining trade flows, it is easy to test equation (4) against the more general form. The general form gives very significant, but significantly different, negative coefficients for the logarithm of population (-.3101, with an absolute t-statistic of 422.0) and for the logarithm of GDP per capita (-.1652 with an absolute t-statistic of 75.1). Thus the results reject the equation (4) constraint that the coefficients are equal. However, if equation (8) of Table 3 is re-estimated using the residuals from the more general form, the resulting coefficients are identical to those based on the residuals of equation (4), to within .0001, so that no conclusions are affected by the inaccuracy of the restriction imposed by equation (4).

10. Backus, Kehoe and Kehoe (1991) undertake more comprehensive tests for scale effects, and find them significant only in manufacturing.

11. The variability of the cross-sectional estimates through time is also a consequence of the fact, well documented by Easterly, Kremer, Pritchett and Summers (1992), that relative growth rates vary much more from year to year than do the structural factors used to explain them. Hence the cross-sectional

parameters are likely to be materially influenced by these short-term factors, given the relatively small sample size.

12. Harrison (1991) found some evidence of level effects and some of change effects in her analysis of several openness measures, but did not attempt to treat them simultaneously. Helliwell and Chung (1991) found some evidence favouring dTI over TI, but also did not test both the joint appearance of both effects.

Table 1
Tests of Parameter Restrictions in the Time-Series Convergence Model

Equation and Restrictions	**Wald Chi Square**	**Degrees of Freedom**	**Probability of restriction**
All estimation by Zellner SUR with instrumental variable estimation for 19 country equations, 1963-89			
Equation (3)			
without cyclical variables ($C_{i,t}$)			
(1) No convergence ($\beta_1=0$, all countries)	124.9	18	<.000005
(2) Equal conv. rates (β_1 equal, all i)	62.1	18	<.000005
(3) No lags ($\beta_2=0$. all i)	104.1	18	<.000005
(4) Equal constants (β_0 equal, all i)	79.1	18	<.000005
(5) (2)+(3)+(4)	662.1	52	<.000005
(6) (1)+(3)+(4)	669.7	53	<.000005
with cyclical variables			
(1) No convergence ($\beta_1=0$, all countries)	428.0	18	<.000005
(2) Equal conv. rates (β_1 equal, all i)	183.3	18	<.000005
(3) No lags ($\beta_2=0$. all i)	455.8	18	<.000005
(4) Equal constants (β_0 equal, all i)	233.7	18	<.000005
(5) (2)+(3)+(4)	1037.4	52	<.000005
(6) (1)+(3)+(4)	1987.7	53	<.000005
Tests for cyclical effects			
(7) Unexpected sales effect=0, all i	2113.0	19	<.000005
(8) Profitability effect=0, all i	134.0	19	<.000005
(9) Inventory disequilibrium effect=0, all i	372.6	19	<.000005
(10) All cyclical effects=0	6101.8	57	<.000005
(11) All cyclical effects equal for each i	744.3	54	<.000005

The inclusion of the cyclical variables lowers the estimated values of the convergence coefficients slightly but insignificantly. The mean of the estimated β_1 across the 18 countries is .098 (SD=.062) without the cyclical variables, and .077 (SD=.062) with cyclical variables. The F-value for the difference between the means is 0.98, far below the 10% significance value of 2.85.

Table 2
Tests of Parameter Restrictions in the Cross-Section Convergence Model

Equation and Restrictions	Wald Chi Square	Degrees of Freedom	Probability of restriction
Estimation by restricted least-squares for 27 cross-sections, 1963-1989, with 19 country observations in each.			
Eq (5) using ln((X+M)/GDP) for trade intensity			
(1) No convergence (β_1=0, all years)	78.9	27	<.000005
(2) Equal conv. rates (β_1 equal, all t)	37.5	26	.06760
(3) No lags (β_2=0. all t)	39.7	27	.05422
(4) Lags equal (β_2 equal, all t)	33.1	26	.15198
(5) Equal constants (β_0 equal, all t)	79.1	26	.00093
(6) (2)+(3)	87.3	53	.00208
(7) (2)+(4)	81.4	52	.00569
(8) No trade effect (β_3=0. all t)	51.5	27	.00301
(9) Equal trade effects (β_3 equal, all t)	43.0	26	.01924
(10) No scale effect (β_4=0. all t)	64.8	27	.00006
(11) Equal scale effect (β_4 equal, all t)	43.0	26	.01924
(12) No trade or scale effects (8)+(10)	139.9	54	<.000005
(13) (9)+(11)	81.4	52	.00569
(14) Slopes constrained (2)+(4)+(9)+(11)	167.2	104	.00008
(15) No lags, constrained (2)+(3)+(9)+(11)	171.4	105	.00005
Repeating tests (8) and (9) using Leamer trade intensity measure			
(8') No trade effect (β_3=0. all t)	37.4	27	.08803
(9') Equal trade effects (β_3 equal, all t)	28.3	26	.34415

Coefficients from Equation (5) with constraints (13), used for results reported in Figures 1 and 2.
Convergence: β_1 = .041316 (SEs range from 5.0 to 14.2 across 27 equations)
Trade effect: β_3 = .007932 (SEs range from 1.8 to 4.5 across 27 equations)
Scale effect β_4 = .006668 (SEs range from 3.3 to 8.4 across 27 equations)

Table 3
Cross-Sectional Tests of Openness Effects in the 1980s

Equation and Restrictions	**Convergence Effect (β_1)**	**Trade Effect (β_3)**		**Scale Effect (β_4)**
Estimation by Zellner SUR for 9 cross-sections, 1981-1989, with 19 country observations in each. Constraints: $\beta_2=0$, β_1, β_3, and β_4 take same values for each year. β_0 differs by year.				
(1) Eq (5) using ln((X+M)/GDP) for trade intensity				
Coefficients	.02509	.00742		.00472
Absolute t-values for constrained coefficients	(3.77)	(2.51)		(3.36)
(2) Eq (5) using Leamer's 1982-based measure of adjusted trade intensity				
Coefficients	.02195	.03175		.00321
Absolute t-values for constrained coefficients	(3.82)	(2.73)		(3.09)
(3) Eq (5) using dln((X+M)/GDP) for trade intensity				
Coefficients	.01983	.06362		.00231
Absolute t-values for constrained coefficients	(2.90)	(1.56)		(2.30)
(4) Eq (5) TI and dTI (cases 1 + 3) for trade intensity		TI	dTI	
Coefficients	.02542	.00721	.05605	.00481
Absolute t-values for constrained coefficients	(3.83)	(2.41)	(1.40)	(3.37)
(5) Eq (5) using TI (case 1) with constrained constants				
Coefficients β_0=-.02501 (2.87)	.03068	.00883		.00564
Absolute t-values for constrained coefficients	(4.59)	(2.95)		(3.98)
(6) Eq (5) using dTI (case 3) with constrained constants				
Coefficients β_0=-.01375 (1.73)	.02377	.14073		.00283
Absolute t-values for constrained coefficients	(3.98)	(3.98)		(2.75)
(7) Eq (5) TI and dTI (cases 5 + 6) with constrained constants		TI	dTI	
Coefficients β_0=-.02784 (3.16)	.03118	.00807	.12914	.00569
Absolute t-values for constrained coefficients	(4.61)	(2.65)	(3.68)	(3.95)
(8) Repeating case (7) using residuals from eq 3 for TI		R	dR	
Coefficients β_0=-.01378 (1.81)	.02915	.00698	.13423	.00311
Absolute t-values for constrained coefficients	(4.27)	(2.25)	(3.76)	(3.20)

Fig 1: Annual Technical Progress
1963-1989, Averages for OECD Countries

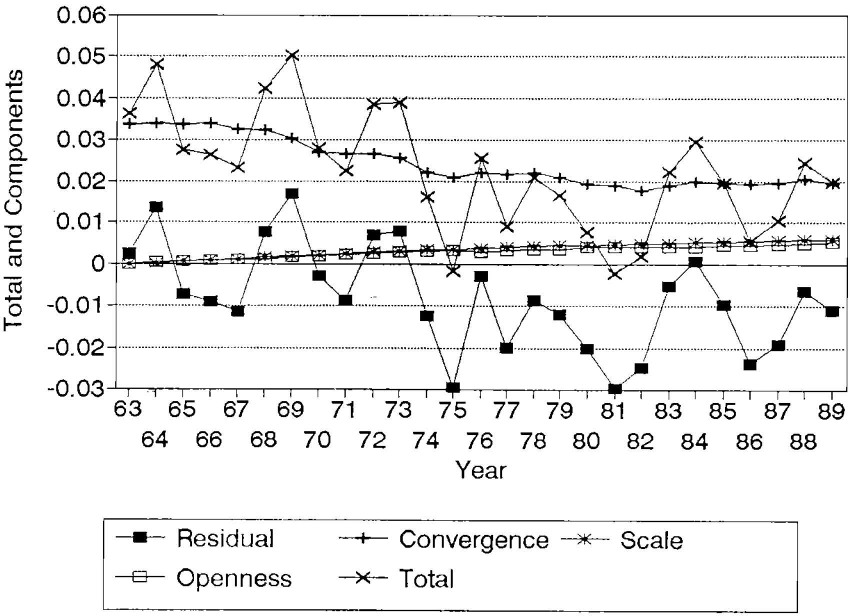

Fig 2: Cumulative Technical Progress
1963-1989, Averages for OECD Countries