PRODUCTIVITY CONVERGENCE IN EUROPE

Efthymios G. Tsionas
Council of Economic Advisers, Ministry of National Economy, Greece

INTRODUCTION

Economic growth is the outcome of a process in which countries strive to catch up with the leaders. Typical neoclassical models in the tradition of Solow [1956], and Cass [1965] have the standard implication that, in terms of long-run macroeconomic behavior, poor economies catch up with richer economies. More specifically, because of diminishing marginal returns to capital, countries with low levels of capital stock will have higher marginal product of capital and, therefore, will grow faster than those with higher levels of capital stock per worker. This catching up process has come to be known as the convergence hypothesis.

This concept of convergence is elaborated in Barro and Sala-i-Martin [1992] and Mankiw, Romer, and Weil [1992]. Both papers emphasize the fact that the neoclassical growth model (either Solow's model or its optimal saving version by Cass) does not imply that all countries reach the same level of per capita income. Instead, countries can reach their respective steady states. Hence, in looking for convergence in a cross-country study, it is necessary to control for differences in steady states of different countries.

Several studies have examined the convergence hypothesis, [Baumol, 1988; Barro and Sala-i-Martin, 1991; Islam 1995; Sala-i-Martin, 1996]. Examples include convergence in per capita income between rich and poor economies [Canova and Marcet, 1995], across different geographical disaggregations [Sala-i-Martin, 1996; Tsionas, 1999a], and across groups of different countries [Lee, Pesaran and Smith, 1997]. Typically, researchers estimate the "convergence equation" for a sample of economies with growth rate of output per capita over some time period (or per worker) to be explained by—among other things—the initial level of output per capita. A finding of statistically significant correlation between initial levels of income and subsequent growth rates has become a popular criterion in judging whether or not convergence has occurred. In this framework a negative correlation is taken as evidence of convergence.

One difficulty with this methodology is that diminishing marginal product of capital means that short-term transitional dynamics, and long-run steady state behavior are mixed up in cross section regressions. Further, the cross section procedures work with the null hypothesis that no countries are converging and the alternative hypothesis that all countries are, which leaves out a host of intermediate cases [Bernard and Durlauf, 1995].

Efthymios G. Tsionas: Council of Economic Advisers, Ministry of National Economy, 5 Nikis Street, Office 607, Constitution Square, 10180 Athens, Greece. E-mail:soe3@compulink.gr

Eastern Economic Journal, Vol. 26, No. 3, Summer 2000

To overcome this problem, Bernard and Durlauf [1995; 1996] and Evans and Karras [1996] suggest tests that examine the long-run behavior of differences in per capita output across countries. These tests define convergence to mean that these differences are always transitory in the sense that long-run forecasts of output differences between any pair of countries converges to zero as the forecast horizon grows to infinity. Convergence, according to this approach, has the weak implication that output differences between any pair of economies cannot contain unit roots or time trends and the strong implication that output levels must be co-integrated with one co-integrating vector of the form (1,-1).

These different convergence tests usually give contradictory results when applied to output series. The traditional tests based on cross-section data generally accept the convergence hypothesis, while the unit roots tests based on time series or panel data sets reject the convergence hypothesis. Thus, an important question in this regard is what should be the appropriate methodology for testing convergence. Quah [1996a; 1996b] suggests a model of polarization of economic growth based on examining the distributional dynamics of economic growth. His main empirical findings show the plausibility of the formation of convergence groups, and some of his empirical evidence show the poor getting poorer and the rich becoming richer. Quah's idea that convergence clubs may exist is important and will be used in the present study.

Most people would accept that the convergence hypothesis is not just a matter of an adequate statistical test. The underlying assumptions of convergence hypothesis are also very important. In particular, a striking feature of almost all previous work on convergence is that they have used the neoclassical growth model using data on per capita output (or output per worker) under the assumption that the economies considered are *closed*. In this model capital is considered to be the main factor that contributes to growth and economies are not permitted to have trade. Thus, this approach produces valid inferences only under ideal conditions. For example, it is not only physical capital that is driving growth. A more complete view of growth, requires an investigation of the mechanism that determines the relative performance of rich and poor economies. It is of paramount interest to know if productivity and, to some extent, technological progress occur differently in poor and rich economies. If this is true, output levels will not tend to converge. According to Dowrick and Nguyen [1989] and Bernard and Jones [1996a] it is very important to examine technological convergence by focusing on total factor productivity (TFP) growth instead of convergence in output per capita or income per capita. If technological convergence does not occur then countries and regions are not catching up, and per capita output in rich and poor countries will tend to lead to increased income dispersion. Other things equal, the technologically backward countries will experience episodes of rapid growth driven by rapid productivity catch-up.

Another point is that the neoclassical growth model is correct when dealing with an open economy where imports are considered to be final goods or they are separable from the primary factors. Burgess [1974] reports that "in this model imports are implicitly assumed to be either final goods which enter the utility function of consumers or intermediate goods which are separable from primary factors (capital and labor) in the productive process" . However, the first assumption (openness) is in conflict with empirical evidence suggesting that the main bulk of imports consists of intermediate goods requiring further processing before delivery to final demand [Burgess, 1974; Denny and May, 1977]. This processing requires the services of domestic primary factors of production, which could be employed elsewhere. The second assumption (separability) implies that the marginal rate of substitution between capital and labor is independent of the quantity of intermediate inputs. It also implies that the elasticities of substitution between intermediate inputs and either capital or labor are equal. However, most empirical studies in the context of European Union (EU) members suggest rejection of the hypothesis that technology is separable with respect to primary factors and intermediate inputs [Apostolakis, 1984]. Hence, *imports cannot be omitted from the neoclassical growth model without producing biased estimates, leading thus to wrong policies and recommendations.*[1]

On the other hand, by excluding imports from the production function we ignore the fact that international trade exerts an influence on the mechanism of aggregate convergence through the transmission of technological knowledge and increased competition [Dollar, Wolf and Baumol, 1988]. Further, Ben-David [1993] offers empirical findings to support the hypothesis that when convergence is found it seems to correspond closely with times of trade reform among trade partners. Thus, in the absence of free trade there is no reason to assume convergence in income levels. In this framework, increasing trade in an economy also increases the knowledge flows from leaders to followers, increases the internal competition and therefore leads to aggregate convergence. Thus, we have to think about the relative contribution of import growth and their impact on the process of convergence.

The present paper proposes a framework for addressing these issues in the context of fifteen European Union (EU) countries, namely Germany, Italy, France, Greece, Sweden, Denmark, Norway, Finland, Austria, Belgium, Netherlands, Portugal, Spain, Ireland and the UK over the period 1960-1997. The motivation for the particular data set has been the celebrated *Maastricht Treaty* according to which EU countries must satisfy certain criteria (in terms of rates of inflation, public debt and exchange rates) in order to join the EMU. However, increasing concerns have been showing up among EU policy makers, politicians and citizens regarding the distinction between nominal and real convergence,[2] the point being that nominal convergence (satisfaction of the Maastricht targets) will not necessarily imply real convergence. On the other hand, the official position of the Union was always that satisfaction of the Maastricht targets is *sine qua non* for balanced and equitable growth in the EU.

The answer to this question is of apparent interest to national policy makers, polers making at the EU level, and economists interested in the implications of nominal convergence for Europe. In this paper, the view that "real" convergence means convergence in productivity growth is adopted. In particular, this paper makes the following contributions:

1. It is investigated whether convergence in total factor productivity (TFP) growth as opposed to convergence in per capita output, has occurred across EU countries from a historical perspective. The methodology is based on specification and estimation of production functions using capital, labor, and imports as production inputs, and allowing for possible existence of non-constant returns to scale.

2. Time and individual effects are introduced in a modified translog production function to allow production functions to differ over time and across countries due to unobservable idiosyncratic components. This approach allows to isolate the effect of "capital deepening" on the one hand and technological and institutional differences on the other, in the process of convergence [Islam, 1995].
3. A country-specific productivity index is estimated, which accounts for (a) differences in managerial ability and technical differentials in production across countries, (b) time-varying intercepts to represent the index of technical change, and (c) country-specific efficiency changes. The index is derived along the lines proposed by Baltagi, Griffin and Rich [1995].
4. Cluster analysis is used to determine groups of EU countries and formally examine productivity convergence within and between groups. Classification into groups is necessary because there are not enough observations (and will never be as a matter of fact) to perform cointegration analysis for the 15 country data set as a whole.
5. Recent econometric techniques are used, appropriate for non-stationary data, to test for convergence and existence of common long-run trends, organized around stationarity testing and maximum likelihood cointegration analysis.
6. Convergence between groups is examined using cointegration analysis when group memberships are not given exogenously but are determined from the data. For the case when group memberships are given exogenously, [Bernard and Durlauf, 1995; Evans and Karras, 1996].

The remainder of the paper is organized as follows: The next section develops the country-specific productivity index followed by a section defining convergense. The econometric methodology for testing convergence is then presented followed by a presentation and discussion of the empirical results. The final section concludes the paper.

TOTAL FACTOR PRODUCTIVITY MEASUREMENT

To arrive at estimates of productivity use is made of the modified translog production function, see Griliches and Ringstad [1971] under the assumption of non-constant returns to scale. For the case of three inputs, it can be written as follows:

$$\begin{aligned}\ln(Y_{rt}/L_{rt}) &= \beta_K \ln(K_{rt}/L_{rt}) + \beta_K \ln L_{rt} + \beta_M \ln(M_{rt}/L_{rt}) + \beta_{KL} \ln K_{rt} + \beta_{KM} \ln K_{rt} \ln M_{rt} \\ &+ \beta_{LM} \ln L_{rt} \ln M_{rt} + \beta_{KK} (\ln K_{rt})^2 + \beta_{LL} (\ln L_{rt})^2 + \beta_{MM} (\ln M_{rt})^2 + \gamma_{KT} \ln K_{rt} T_t \\ &+ \gamma_{LT} \ln L_{rt} T_t + \gamma_{MT} \ln M_{rt} T_t + \sum_r \lambda_r D_r + \eta_t D_t + U_{rt}.\end{aligned}$$

This function has been chosen for two reasons. *First*, it behaves much better when compared to a usual translog. Likelihood ratio tests strongly favor the above specification over translog alternatives and its variants. *Second*, this production function will provide us with a country-specific productivity index that refers to output per unit of labor. This seems to be a much more reasonable measure to use in international comparisons, compared to a productivity index derived from a total output measure.

In this model, given a sample of $n = 15$ EU countries for T=38 years from 1960 to 1997, the countries are assumed to produce a single output (Y_{rt}) from inputs of capital (K_{rt}), labor (L_{rt}) and imports (M_{rt}). T is a general index of technical change scaled to zero in the initial year (i.e., T_1=0. D_r and D_t are country specific ($r = 1,2,....n$) and time specific dummies ($t = 1,..,$T) respectively). Finally, U_{rt} is the usual statistical noise.

Productivity growth can be measured using the concept of country-specific productivity index (CSPI) that has been proposed by Baltagi, Griffin and Rich [1995] in the context of measurement of technical change. The definition of the index is

$$CSPI_{rt} = \lambda_r + \eta_t + U_{rt},\ r = 1,..., n;\ t = 1,..., T \tag{2}$$

In equation (2), the fixed effects coefficient λ_r can be interpreted as differences in managerial ability and average technical differences in production across countries. The fixed effects capture differences in access to high quality factors of production, and in ability to utilize the latest technologies and inherited capital stock and technologies. Coefficient η_t is a time-specific intercept that represents the index of productivity. Finally, the U_{rt} term reflects intertemporal, country-specific efficiency changes.

The advantage of the *CSPI* compared to other measures of productivity, is that *it does not make arbitrary assumptions about the functional form of productivity.* In particular, it overcomes the problem of assuming that technical progress must be a parametric function of the time trend. In essence this is a semi-parametric index, which is highly desirable in our application because we do not want our convergence results to depend critically on the functional form of the trend. For more details, see Baltagi, Griffin and Rich [1995] and Tsionas [1999b].[3]

From an inspection of fixed effects it appears that Spain has the greatest value of *CSPI*, while the UK has the least. Although this seems to suggest that Spain is the most "productive" country in the sample it should be kept in mind that *TFP* and *CSPI* could have substantial differences in practice. For example, Baltagi, Griffin and Rich [1995] in their study of the airline industry find that local carriers with significantly less activity than large carriers seem to perform extremely well according to their index (which is the equivalent of *CSPI*) but perform badly according to *TFP* rankings. The reason is that *CSPI* measures efficiency change *conditionally* upon output differences and industrial structure (which would be the equivalent of "route structure" as mentioned in the concluding section of Baltagi, Griffin and Rich [1995]) contrary to *TFP*. In this sense, it is more reasonable to think of *CSPI* as a "catching-up effort" variable, which has to be relatively large for countries like Spain and relatively low for countries like the UK.

To obtain estimates for CSPI defined in equation (2), equation (1) is estimated by the maximum likelihood (ML) method, and substitutes the estimated parameters in equation (2). The ML technique is suitable for the estimation of panel data models with individual and time effects.[4] Estimation results of production function (1) are supplied in Table 1. For the nature and the structure of the variables used, see Appendix A.[5]

TABLE 1
ML Estimates of Production Function Parameters

Parameter	Estimate	Fixed Effect Coefficients	Estimate
β_K	1.812[a] (0.431)	Belgium	-0.218 (0.206)
β_L	0.526 (0.745)	Denmark	0.067 (0.212)
β_M	-1.063[a] (0.268)	Greece	0.546[a] (0.211)
β_{KL}	-0.695[a] (0.047)	Spain	1.275[a] (0.229)
β_{KM}	-1.811[a] (0.018)	France	0.605[a] (0.115)
β_{LM}	0.672[a] (0.032)	Ireland	0.586[c] (0.318)
β_{KK}	0.853[a] (0.019)	Italy	0.019 (0.105)
β_{LL}	0.086[a] (0.032)	Netherlands	-0.484[a] (0.182)
β_{MM}	-3.538 (2.941)	Portugal	0.476[a] (0.197)
δ_{KT}	0.028[a] (0.002)	UK	-0.600[a] (0.149)
δ_{LT}	-0.009[a] (0.001)	Austria	0.226 (0.196)
δ_{MT}	-0.033[a] (0.001)	Norway	-0.024 (0.227)
		Sweden	0.147 (0.183)
Log-Likelihood	825.814	Finland	-0.431[b] (0.223)
		Germany	0.135[a] (0.082)

Time coefficient estimates are not reported here but are available upon request from the authors. Numbers in parentheses are standard errors. a indicates statistical significance at 1 percent, b at 5 percent, and c at 10 percent levels.

DEFINITION OF CONVERGENCE

Following Bernard and Durlauf [1995] we define convergence by examining the time series properties of the productivity index (CSPI). According to their definition 2.1' countries $p = 1,.., n$ converge if the long-term forecasts of productivity for all series are equal at a fixed time t:

$$\lim_{\tau \to \infty} E(x_{1,t+\tau} - x_{p,t+\tau} \mid F_t) = 0, \; p \neq 1, \qquad (3)$$

where F_t is the information set available at time t. Bernard and Durlauf [1995] allow for the possibility that countries do not converge, yet they respond to the same permanent shocks, perhaps in a different manner. This gives rise to their Definition 2.2' which involves examining common trends in productivity, (i.e., persistence). This involves requiring that countries $p = 1,..,n$ contain a single trend in the sense that long-term forecasts are proportional at a fixed time t. If

$$\bar{x}_t = [x_{2,t}\, x_{3,t} \ldots x_{n,t}]$$

we must have:

$$\lim_{\tau \to \infty} E(x_{1,t+\tau} - a'\bar{x}_t) = 0. \qquad (4)$$

If x_t denotes the nx1 vector of productivities, then in the vector error correction representation

$$\Delta x_t = \Gamma(L)\Delta x_t + \Pi x_{t-1} + e_t. \qquad (5)$$

If the rank of Π is r $(0 < r < n)$ there are r cointegrating vectors and therefore the group contains $n - r$ common stochastic trends. If the rank of Π is zero, there is no cointegration (there are n stochastic trends) and the long-run productivity levels are not related, (i.e., they are being driven by n independent random walks). Convergence requires $n-1$ cointegrating vectors of the form $(1,-1)$ so that there exists a single, common long-run trend. If the number of cointegrating vectors is r $(0 < r < n)$ there is no strict convergence, yet there are common trends. The examination of the nature of common trends in the data is important in its own right, provided their number is small. (See the concluding section of Bernard and Durlauf [1995] for details.)

On the negative side, it must be noted that these definitions of convergence do not necessarily imply that the series are integrated or that they are cointegrated. If, for example, $x_{1t} = x_{1t-1} + \varepsilon_t$ and $x_{2t} = x_{1t} + \lambda^t + u_t$ with $\lambda \in (0,1)$ and u_t, ε_t are standard zero-mean white noise processes, it follows that $E(x_{2,t+\tau} - x_{1,t+\tau} \mid F_t) = \lambda^{t+\tau}$ which vanishes as $\tau \to \infty$. Here, F_t denotes the information set of date t. A closely related issue is the criticism of Riezman, Tamura and Whiteman [1993] who argue that the cointegration-based tests of convergence are tests of the hypothesis that "convergence has occurred" rather than the hypothesis that "convergence is occurring".[6] For a Monte Carlo investigation of the power of Johansen's test in this situation, see Appendix B.

TABLE 2
Cluster Analysis

Country	Cluster 1	Cluster 2	Distance	Country	Cluster 1	Cluster 2	Distance
1. Belgium	*		0.394	9. Portugal	*		0.282
2. Denmark		*	0.107	10. U.K.	*		0.173
3. Greece		*	0.254	11. Austria		*	0.121
4. Spain	*		0.478	12. Norway		*	0.138
5. France	*		0.157	13. Sweden		*	0.095
6. Ireland	*		0.210	14. Finland		*	0.448
7. Italy		*	0.152	15. Germany	*		0.234
8. Netherlands	*		0.156				

PRODUCTIVITY RELATIONSHIPS

Group Formation

Although CSPI solves the problem of productivity measurement in a consistent manner, it does not address the problem of identifying economies with common laws of motion. It is well known that countries differ widely in terms of social, political and institutional characteristics. As a consequence, assuming homogeneity in a given sample of countries is an inappropriate way to investigate the convergence hypothesis. *The reason that we need to classify countries into groups is related to the number of degrees of freedom*. There are 38 annual observations and 15 countries. If a vector error correction model is specified with all 15 countries and 2 lags, there would be negative degrees of freedom left. Therefore, one has to be wiser in using the available data.

To that end, and in order to identify economies whose growth behavior obeys a common statistical model cluster analysis is used to identify those groupings across which productivity estimates differ widely. Cluster analysis is performed on differences of *CSPI* using the K-means algorithm.[7] The reason is that unit root tests (see next section) indicate that *CSPIs* are non-stationary in levels. Since no statistical theory details the distributional properties of maximum likelihood factor analysis when series can be non-stationary, we are forced to induce stationarity by a data transformation (namely first differencing).

Table 2 presents the outcome of the clustering process, (i.e. country memberships). The table indicates that two sets of countries exist. The first group (group I) includes Germany, France, Belgium, Netherlands, Portugal, Spain, Ireland and UK while the second group (group II) comprises Italy, Greece, Sweden, Denmark, Norway, Finland and Austria. This sorting is robust. In particular, when the number of clusters is set to three the primary two groups remain unchanged. The only difference is that Spain moves from group I and forms a new, third group of its own. Providing an explanation for this clustering of countries is particularly difficult. For example, Spain and Portugal are in group I along with technological leaders such as

TABLE 3
Unit Root Tests

Country	PRODUCTIVITY SERIES Augmented Dickey-Fuller Levels	Diff.	Phillips-Perron Levels	Diff.	INFLATION SERIES Augmented Dickey-Fuller Levels	Diff.	Phillips-Perron Levels	Diff.
1. Belgium	−2.18	−1.70	−2.20	−5.73	−0.28	−3.92	−0.23	−6.22
2. Denmark	−1.31	−2.01	−1.33	−6.04	−2.11	−2.02	−2.85	−3.90
3. Greece	−2.04	−3.10	−2.20	−6.40	−1.90	−1.34	−2.07	−4.61
4. Spain	−2.54	−2.41	−3.02	−6.02	−2.52	−2.05	−2.53	−4.57
5. France	−2.18	−5.14	−2.37	−5.15	−2.79	−4.73	−2.96	−5.43
6. Ireland	−1.37	−3.68	−1.40	−6.17	−0.03	−1.29	−0.28	−4.18
7. Italy	−0.93	−3.01	−0.93	−6.14	−2.73	−3.33	−3.07	−4.28
8. Netherlands	−1.54	−3.04	−1.69	−4.12	−1.77	−3.89	−2.43	−6.38
9. Portugal	−2.62	−3.89	−2.62	−7.13	−1.57	−4.38	−1.45	−5.65
10. U.K	−1.96	−2.39	−1.43	−6.69	−1.54	−2.65	−1.67	−4.77
11. Austria	−2.44	−2.28	−1.94	−4.03	−1.52	−3.28	−1.62	−5.36
12. Norway	−2.60	−2.70	−1.52	−6.38	−0.56	−3.17	−0.92	−7.80
13. Sweden	−1.98	−2.27	−2.59	−5.90	−2.21	−3.38	−2.27	−6.03
14. Finland	−2.51	−4.55	−2.53	−7.94	−2.24	−3.69	−2.22	−7.39
15. Germany	−1.21	−2.65	−2.21	−5.38	−1.77	−4.13	−2.17	−4.21

"Augmented Dickey-Fuller" is the Augmented Dickey-Fuller t-test for a unit root in the constant/no-trend model. The Phillips-Perron test applies to the same model. The 10 percent critical value for Dickey-Fuller and Phillips-Perron test statistics is minus 3.13. Number of lags was selected optimally using the Schwarz criterion. In all cases, underlined values denote sampling evidence against a unit root.

Germany and the UK, while Scandinavian countries comprise the second group, along with traditional members of the "southern block" such as Italy and Greece. Although a satisfactory explanation is not available, it should be noted that such orderings are not uncommon in empirical research, [Hobijn and Franses, 1998].[8]

In what follows, group "factors" means factors extracted in each group using factor analysis. For each group, group memberships are those which were produced by the clustering process.

Stationarity Tests

First, tests for stationarity of the country-specific productivity index (CSPI) are conducted. Table 3 presents unit root test statistics for all data series. Results are reported for the augmented Dickey and Fuller [1981] and the Phillips-Perron [Perron, 1989] tests. Augmented Dickey-Fuller (ADF) and Phillips-Perron tests for the levels model, are all consistent with the hypothesis of a unit root type of non-stationarity in the data. The results in Table 3 also suggest that in all fifteen countries, productivity levels contain a unit root implying that these series may be I(*1*). To see whether they are in fact I(2), ADF and Phillips-Perron tests are used in first differences. The result is that, according to the ADF statistic, several series seem to contain a unit root in first differences. According to the Phillips-Perron statistic this is decisively not the case. This could be attributed to the fact that the ADF test does not fully account for the autocorrelation properties of residuals in ADF regressions. The Phillips-Perron test corrects non-parametrically for such autocorrelation.

Therefore, it can be assumed that there is no unit root in first differences and, therefore, productivity series are $I(1)$. According to the Phillips-Perron test for non-stationarity of inflation (reported in the same table) all inflation series are $I(1)$ and their differences are stationary. Of course, stationarity tests must be viewed with caution because the sample length is small, while critical values widely available are asymptotic. This is a problem for many other empirical researchers as well, who are forced to work with annual macroeconomic data. Stationarity tests, however, even if not taken literally, do suggest that $I(1)$ non-stationarity is acceptable at least as a working hypothesis.

An issue that arises in connection with production function estimation is that the CSPI measures were found to contain unit roots. This implies that the residuals of production functions contain unit roots (since λ_t and η_r are constants) and therefore the possibility arises that the estimated production function could be spurious. One should, at this point, consider the alternatives. An anonymous referee pointed out that "the problems above are precisely why previous researchers interested in *TFP* have not attempted to estimate the production function parameters but instead have imposed parameters on the data to generate the *TFP* series." Although this is a reasonable approach, it is difficult to assign production function parameters for each and every one of the fifteen countries in this sample without generating suspicions that the results might be very sensitive to alternative parameterizations. One should think about why the problem of spurious regressions arises in the first place. The reason is that we are forced to use a two-step approach. First, production functions are estimated in order to obtain *CSPI*, and then *CSPI*'s are used in cointegration modeling to perform convergence inferences. But in order to do cointegration we need a unit roots assumption that invalidates the first step. The way out is, of course, to use panel cointegration techniques for all fifteen countries to examine common trends, but the large number of countries is prohibitive for this kind of analysis. Therefore, although the two-step approach is not the best approach possible, it seems to be the only approach that is feasible for this data set. The *deus ex machina* would be, of course, having more time observations, but this is not under our control.

Econometric Methodology for Testing Convergence

The maximum likelihood methodology of cointegration, developed by Johansen [1988] is used to test for convergence. To establish notation, the system contains endogenous variables x and exogenous variables z:

$$x_t = \sum_{i=1}^{m} \pi_i x_{t-i} + \sum_{j=0}^{r} \Gamma_j z_{t-j} + v_t, \quad v_t \sim N(0,\Omega) \tag{6}$$

where x_t is $n\times 1$ and z_t is $m\times 1$. It is known that this can be written in the form

$$(I - \pi(L))x_t = \Gamma(L)z_t + v_t. \tag{7}$$

TABLE 4
Cointegration Results for Group 1

Ho:rank	CASE A. NO EXOGENOUS VARIABLES Johansen trace statistic	CASE B. OIL DUMMY INCLUDED AMONG THE EXOGENOUS VARIABLES Johansen trace statistic
p = 0	172.9	183[b]
p≤ 1	100.3	113.2
p≤ 2	65.33	67.00
p≤ 3	39.98	36.27
p≤ 4	24.85	22.53
p≤ 5	11.60	12.82
p≤ 6	5.91	4.36
p≤ 7	1.91	1.75

The Johansen trace statistic is computed with a Bartlett correction for degrees of freedom for better performance in finite samples. b denotes statistical significance at the 1 percent level.

When it is known that variables in x_t are $I(1)$ one can work with the error correction representation [Engle and Granger, 1987] given by:

$$\Delta x_t = \sum_{i=1}^{m-1} \gamma_i \Delta x_{t-i} + \Pi x_{t-m} + v_t \tag{8}$$

assuming for simplicity the presence of no exogenous variables.

If $rank\ (\Pi) = p < n$ then $\Pi = \alpha\beta'$ where α and β are nxp matrices of rank p, and $\beta' x_t$ denotes the long-run I(0) cointegrating relationships. The I(0) representation is:

$$\Delta x_t = \sum_{i=1}^{m-1} \delta_i \Delta x_{t-i} + \alpha(\beta' x_{t-1}) + v_t \tag{9}$$

EMPIRICAL RESULTS

Within and Between Group Unconditional Convergence

The empirical results for group I are reported in Table 4. Case A reports results for a vector error correction (VEC) system without exogenous variables. When an oil crisis dummy is included in the set of exogenous variables, the results are presented in case B of the same table. Cointegration analysis is conducted using the maximum likelihood methodology of Johansen [1988]. (See also Johansen and Juselius [1990]). This table reports the Bartlett-corrected version of Johansen's trace test. This test has better small-sample performance. All computations have been performed using PcGive and PcFiml [Doornik and Hendry, 1994].

Before proceeding it must be noted that prior to testing for convergence, countries in the data have been divided into two groups using cluster analysis. This has implications for the true critical values of subsequent statistical work, because it introduces a classical pre-testing problem: First, a statistical test is used to make a

TABLE 5
Cointegration Results for Group II

	CASE A NO EXOGENOUS VARIABLES	CASE B OIL DUMMY INCLUDED AMONG THE EXOGENOUS VARIABLES
Ho:rank	**Johansen trace statistic**	**Johansen trace statistic**
p = 0	103.8	113.1
p≤ 1	71.28	76.41
p≤ 2	42.53	48.61
p≤ 3	22.89	28.22
p≤ 4	10.32	12.69
p≤ 5	3.76	4.20
p≤ 6	0.30	0.25

The Johansen trace statistic is computed with a Bartlett correction for degrees of freedom for better performance in finite samples.

decision and, depending on the decision, other statistical tests are performed.[9] As is well known, asymptotic distributions of parameters resulting for pre-tests are finite mixtures of normal distributions. Deriving the true critical values of Johansen rank tests when cluster analysis pre-testing has been performed is a highly non-standard application, which also involves unresolved issues in bootstrap analysis of cointegration analysis. For this reason, it is better to use existing and widely available critical values with some conservatism and follow the Bayesian advice: use significance levels that decrease as the sample length increases. In this study, practical application of this advice implies testing whether results are reasonably robust to significance levels lower than 5 percent, for example 1 percent. Pre-tests are usual in empirical work on convergence, (see for example Durlauf and Johnson [1995] who employed regression trees to classify their sample into groups, and then regressed labor productivity onto certain variables for each group).

Turning to presentation of results, from case A of Table 4 it is seen that the null of $p = 0$ (no cointegration) cannot be rejected by any test. From case B (when an oil dummy is included as an exogenous variable in the VEC) the null of $p = 0$ can be rejected. The null of $p \leq 1$ is not rejected (trace statistic equals 113.20 against a 95 percent critical value of 124.2). It would seem safe to conclude that $p \leq 1$. Overall, for group I it appears that there are too many common stochastic trends (idiosyncratic elements) and, therefore, *one can decisively reject the hypothesis of convergence*.

Panels A and B of Table 5 report Johansen cointegration tests for group II. When no exogenous variables are included in the model (case A) the test does not reject that $p = 0$, (i.e., that there is no cointegration). When the oil dummy is included the conclusion remains robust. It appears then that $p = 0$ for group II productivity series, leading naturally to *rejection of the convergence hypothesis*. For this group, individual productivity series seem to be just independent random walks. Again, group II has too many indiosyncratic elements as well.

TABLE 6
Cointegration Results for Group Convergence
No Exogenous Variables

Ho:rank	Johansen Trace Statistic
p = 0	7.99
p≤ 1	0.49

The Johansen trace statistic is computed with a Bartlett correction for degrees of freedom for better performance in finite samples.

In view of the fact that convergence was rejected for each group, it is not meaningful to test for between-group convergence. The reason is that since relatively homogenous economies (economies within a group) do not converge, more dissimilar economies (economies in different groups) cannot converge because this would contradict absence of within-group convergence.

There is, however, a possibility that too many idiosyncratic elements (common trends) have been found because of measurement errors whose effect would be minimized had we used data in a higher level of aggregation, (i.e., group data). Cointegration results for groups I and II treated as separate entities are reported in Table 6. Johansen's trace test is compatible with the null of $p = 0$ (the test equals 7.99). Therefore the group productivity series are not converging because there are two, not one, common long-run trends. In other words, even group-wide productivities are unrelated random walks. Therefore, the earlier finding that there is too much idiosyncrasy in European productivity to justify convergence, is real.

Diagnostics statistics for the VEC are reported in Table 7. For the first group (panels A and B) the only problems seem to be vector autocorrelation—*p*-values are near 2 percent and 7 percent for the first group and 2 percent and 4 percent for the second group. Therefore, the group VEC systems seem to be data congruent and free from specification-error deficiencies.

Turning attention to α coefficients, which show feedback from $\beta' x_t$ on the group productivity factors, these are -0.695 and 0.277 for group I and group II respectively, with standard errors 0.137 and 0.099. Thus, α coefficients are highly statistically significant, implying *significant error correction adjustments in productivity effort.* The elements of the long-run matrix and their standard errors are as follows.

$$
\begin{array}{cc}
-.695 & .461 \\
(.137) & (.09) \\
.277 & -.183 \\
(.09) & (.066)
\end{array}
$$

These estimates show, first of all, a statistically significant impact from each group's own shocks and, second, a negative long-run impact of one group's productivity shock to the productivity factor of the other group. It is important to note that the adjust-

TABLE 7
Multivariate Diagnostic Statistics for Groups

Test	Group I VEC (8 equations)		Group II VEC (7 equations)	
CASE A. NO EXOGENOUS VARIABLES				
Vector Portmanteau (1 Lags)	66.075		42.09	
Vector AR	1.61[a]	[0.02]	1.59[a]	[0.03]
Vector Normality	18.29	[0.31]	13.17	[0.51]
Vector X-squared	1.31	[0.33]	1.27	[0.33]
CASE B. OIL DUMMY INCLUDED AMONG THE EXOGENOUS VARIABLES				
Vector Portmanteau (1 Lag)	65.30		44.2	
Vector AR	1.49[a]	[0.07]	1.54[a]	[0.04]
Vector Normality	15.08	[0.52]	7.57	[0.91]
Vector X-squared	1.36	[0.32]	1.92	[0.14]

See Lutkepohl [1991] for the vector portmanteau test, Godfrey [1988] for the vector autocorrelation test, Kelejian [1982] for the vector functional form misspecification test. For the vector normality test see the discussion in Doornik and Hendry [1994, 216]. For the ARCH test see Engle [1982]. Figures in brackets represent asymptotic p-values associated with the tests. a denotes significance at the 5 percent level.

"Vector portmanteau" is a multivariate version of the usual portmanteau statistics. "Vector AR" tests the null hypothesis that system residuals follow a vector autoregressive scheme of order one. "Vector normality" tests the null hypothesis of multivariate normality. "Vector X-squared" is a Lagrange-multiplier statistic to test the null hypothesis that there is functional form misspecification which reduces to omission of the squares of variables from the VEC system.

ment coefficient to long-run equilibrium for group I is more than three times greater than the same coefficient for group II. This implies that it takes about a year and a half for group I to close the productivity gap from the long-run equilibrium and more than five years for the second group to do the same! In other words, *there is a true productivity growth gap in the European Union.*

The cross-effects are, of course, differential. The effect from group II on group I is larger, indicating that productivity shocks in group II have a larger impact on group I's productivity, meaning that the first group reacts more to productivity shocks elsewhere in the Union, compared to the second group.

Conditional Convergence

This section examines whether both set of countries converge to different steady-states, (i.e., does conditional convergence hold?). To investigate the possibility of conditional convergence, group-wide inflation rates have been computed for each group using the first principal component of the individual time series.[10] The inclusion of this variable is motivated by the following fact: One of the main objectives of the EU is to obtain similar low inflation rates across all EU countries. The inflation rate is expected to have an inverse relationship with productivity growth. Thus, an increase in the inflation rate is expected to exert a negative influence on productivity growth.

TABLE 8
Cointegration Results for Group 1

Ho: rank=p	Case A All variables enter as restricted Johansen trace statistic	Case B All variables enter as unrestricted Johansen trace statistic	Case C Only prices enter as unrestricted Johansen trace statistic
p = 0	413.5[b]	249.5[b]	275.3[b]
p≤ 1	319[b]	183.3[b]	206.3[b]
p≤ 2	241.4	129.2[b]	146.9[b]
p≤ 3	176.3[b]	83.81[b]	99.41[b]
p≤ 4	120.6[b]	52.97[b]	64.36[b]
p≤ 5	81.19[b]	27.02	35.47[a]
p≤ 6	46.25[b]	11.77	15.72
p≤ 7	18.58[b]	0.40	3.69

a. Significant at the 5 percent level.
b. Significant at the 1 percent level.

Of course, these countries follow a variety of monetary policy regimes for which principal components have been computed. For this reason, computing a single principal component for their inflation rates may be problematic. It is, however, the only available approach. If monetary policy were to be formally included in VECs, too few degrees of freedom would be left to conduct cointegration tests with any reasonable precision, given that annual data are being used. On the positive side, convergence of the majority of European countries towards the EMU provides a homogeneity factor that gives an aura of reasonableness to principal component analysis.

Increased inflation may adversely affect productivity growth for a number of reasons [Jaret and Selody, 1982]. First, inflation may affect labor productivity by causing an inefficient mix of factor inputs. Second, inflation reduces the information content of price signals, thus decreasing the reliability of absolute price measurements to reflect price changes accurately. With loss of information upon which to base their decisions, business managers will make more errors and hence will more often choose sub-optimal factor input mixes and sub-optimal types of capital. Finally, increasing uncertainty about inflation can decrease productivity by inducing firms to increase their inventories of "unproductive" buffer stocks and to reduce their expenditures on long-term basic research.

To test for convergence conditionally on inflation, vector error correction (VEC) models must be specified and estimated for countries in groups I and II. If conditional convergence is found, we subsequently must specify and estimate VEC models for aggregate, group-wide productivity factors conditionally on group-wide inflation factors. Three cases are specified regarding the specification of VEC models. The *first* is when all variables (constant, oil crisis dummy and price variables) are restricted to lie in the cointegrating space. The *second* is when they do not lie in the cointegrating space and, the *third* is when only prices are restricted to lie in the cointegrating space. For group I, the results are reported in panels A, B and C of Table 8. In the first case the null hypothesis that the rank of Π is $p \leq 7$, can be rejected.

TABLE 9
Cointegration Results for Group II

Ho: rank=p	Case A All variables enter as restricted Johansen trace statistic	Case B All variables enter as unrestricted Johansen trace statistic	Case B Only prices enter as unrestricted Johansen trace statistic
	NATURE OF COINTEGRATION SPACE		
p = 0	358.5[b]	175.2[b]	19.9[b]
p≤ 1	218.2[b]	120.4[b]	136.7[b]
p≤ 2	159.7[b]	84.18[b]	98.83[b]
p≤ 3	109.3[b]	49.39[a]	62.61[b]
p≤ 4	66.29[b]	21.92	33.95
p≤ 5	35.81[b]	5.93	13.31
p≤ 6	13.84[b]	0.24	4.99

a. Significant at the 5 percent level.
b. Significant at the 1 percent level.

Since $p = 8$, there must be no common long-run stochastic trends, implying that we should reject the conditional convergence hypothesis. When variables do not lie in the cointegrating space (case B) Johansen's trace test indicates that $p \leq 5$ cannot be rejected and therefore there are three common trends. From case C (only the constant and the oil dummy are allowed in the cointegrating space) it seems there are two common long-run trends.[11]

These results show that convergence inference is sensitive to assumptions about the nature of the cointegrating space. However, it seems plausible to conclude that productivities in group I are characterized by a small number of common long-run trends, usually zero to three. *It is important that conditioning on inflation does not imply convergence, yet lowers the number of common trends considerably*, from seven or eight to about two or three. Thus, inflation does help the "cohesion" process, although its impact is not tremendous enough to generate one common stochastic long-run trend from the mosaic of European productivities.

The same picture emerges from Table 9 where results are reported for countries in group II. When prices are forced in the cointegrating space, it is found that there are no common trends and thus no convergence, (i.e., $p = 7$, the number of countries in that group). When no variable is allowed in the cointegrating space (case B), three common trends are found. When only the constant and the oil crisis dummy are allowed in the cointegrating space (case C) three common trends are again found, (i.e., $p = 4$). *Therefore, productivities in group II are characterized by a number of common trends although it cannot be claimed that there is a unique common trend to support the conditional convergence hypothesis.*

Despite the fact that within-group conditional convergence does not seem to occur, one may nevertheless argue that this is due to measurement error in the data or differences in the relative quality of country-specific data. If this is correct, when the data is aggregated and group-wide factors are computed in the context of between-group convergence, one should find evidence in favor of convergence. Relevant results are reported in Table 10. The only case where it can be argued that the rank of

TABLE 10
Between Group Convergence

Ho: rank=p	Case A All variables enter as restricted Johansen trace statistic	Case B All variables enter as unrestricted Johansen trace statistic	Case B Only prices enter as unrestricted Johansen trace statistic
	NATURE OF COINTEGRATION SPACE		
p = 0	128.9[b]	24.78[b]	126.9[b]
p≤ 1	21.41[b]	2.06	19.88[b]

b denotes significance at the 1 percent level.

the long-run matrix Π is $r = 1$ (so that there is a single common trend in group-wide, aggregate productivities) is in case B where it is assumed that no variables enter the cointegrating space. In the other two cases the rejection of the conditional convergence hypothesis seems fairly clear-cut. Although the number of common long-run trends is sensitive to assumptions about the nature of the cointegrating space, rejection of the convergence hypothesis seems more likely.

Vector misspecification statistics are shown in Table 11 for both the VECs in groups I and II as well as the VEC that refers to between-group convergence. With the exception of marginal autocorrelation in group I no other problems seem to exist. It is notable that single-equation diagnostics (available on request) did not reveal any problems at all, so the (very marginal) significance of the above test, seems to be accidental. Therefore, the sensitivity of convergence inference cannot be attributed to the fact that estimated VECs are not data-congruent.

DISCUSSION

In order to advance economic and monetary cooperation among European countries, and to speed up integration, the Maastricht treaty was signed on 7 February 1992 and came into effect on 1 November 1993. The main purpose of the Maastricht Treaty is the replacement of the member countries' independent monetary policy bodies by one single authority, the European Central Bank. Eligibility for acceptance into the EMU is conditioned on members undertaking policies aimed at achieving economic convergence which is considered a prerequisite to monetary union. Thus, achieving a high degree of sustainable convergence was deemed of paramount importance and seen as naturally evolving from convergence in exchange rates, inflation rates, long-term interest rates and government finances. Around these criteria country members would devise policies leading to convergence in per capita GNP, which of course constitutes the ultimate goal of the EU. However, this view anticipates convergence of productivity growth and ignores the crucial role of TFP on GNP convergence. Crafts [1992], for example, reports that TFP and not capital accumulation was by far the most important reason for slower growth in the UK from 1950 to 1973. Moreover, Gordon [1992] pointed out that two European countries —the UK and Italy— experienced a two-stage slowdown in manufacturing productivity growth over

TABLE 11
Vector Diagnostic Statistics for VEC Models

Test	Group I VEC (8 equations)		Group II VEC (7 equations)		Between-groups VEC (2 equations)	
Autocorrelation	2.2257	[.017][a]	1.5707	[.247]	1.079	[.392]
Normality	15.576	[.483]	11.046	[.682]	5.28	[0.26]
Functional form (squares)	---		---		.726	[.749]
Functional form (cross-products)	---		---		.755	[.773]

p-values appear in brackets beside each test. a denotes significance at the 5 percent level.
"Autocorrelation" tests for a VAR specification of orders 1-2. "Functional form (squares)" tests that the squares of endogenous variables have been incorrectly omitted from the specification. "Functional form (cross-products)" tests that the squares and cross-products of endogenous variables have been incorrectly omitted from the specification. Functional form misspecification statistics are not reported for VECs in groups I and II because these statistics could not be computed due to a deficit in the degrees of freedom.

the sub-periods 1961-72, 1972-79 and 1979-1988, with worse performance in the third period compared to the second. This result implies that convergence must have ceased during these periods, at least in manufacturing. In this context the statistical examination of productivity convergence *per se* in the EU as well as the examination of the relationships among factors that affect productivity convergence becomes a central issue.

There is no compelling reason to expect productivity levels that vary within each and every economy to suddenly assume patterns of strong convergence across all EU members. Different institutional characteristics, different technological conditions, different sectoral sizes, and different variations of economic performance are some of the factors that are responsible for a mosaic of behaviors, not all of which obey the same patterns of growth. To this end, the present study distinguishes two groups of (more or less) homogeneous countries based on their productivity effort and it examines whether convergence in productivity occurs between or within groups. The first group (group I) includes Germany, France, Netherlands, Belgium, Ireland, Spain, Portugal and UK while the second group (group II) consists of Denmark, Sweden, Finland, Norway, Italy, Austria and Greece. The empirical findings suggest that in both groups I and II countries do not converge in terms of productivity. This means that the TFP gap within each set of countries tends to increase over time.

Between groups I and II, divergence in relative productivity levels is the dominant feature. A possible explanation for this situation is that the benefits of technology in particular, and of learning in general, are not as freely transferable within groups as between groups, thus resulting in different group-specific steady state productivity levels. This seems to be the main obstacle that the "Maastricht mentality" will find in its way: Although satisfaction of the Maastricht targets *might* help real convergence, we should not expect miracles in terms of closing the productivity gap between the technology leaders and the technology followers of the EU, *unless* miracles

can be guaranteed in terms of better access of followers to leading technology. This is not an issue of legislation but rather a matter of changing institutions in both groups members so as to facilitate technology adoption and advance their ability to use the advanced technology already available to the groups' members.

The crucial question is *whether* real convergence can be achieved by the Maastricht criteria. Our empirical results suggest that groups are not converging conditionally on inflation. What this means is that the inflation objective of the Maastricht Treaty does not build a strong base for eliminating productivity gaps among EU members. We find, however, that conditioning on inflation lowers the number of common trends considerably. Unconditionally on inflation, there is too much idiosyncrasy (seven or more common trends). Conditionally on inflation, about two common trends seem to emerge. Therefore, the Maastricht process will definitely help cohesion of European productivities although one should not expect perfect convergence (i.e., the emergence of a single, common, stochastic long-run trend).

Empirical results show that the adjustment coefficient to long-run equilibrium for group I is more than three times greater than the same coefficient for group II. This means that it takes about a year and a half for group I to close its productivity gap from the long-run equilibrium and more than five years for the second group to do the same. Therefore, a true productivity gap exists in the EU and it requires further European policies in promoting the technological development of the two groups and especially of the second group. The role of these policies will be crucial for real convergence.

CONCLUSIONS

This paper attempted to examine real convergence and its association with Maastricht-type nominal convergence for fifteen countries of the EU from 1960 to 1997. The papers departed from the traditional view of examining convergence in per capita output or per capita income and identified real convergence with convergence in TFP growth.

The paper has applied the idea of productivity convergence in a modified translog production function where in addition to primary inputs, capital and labor, imports are also included in the production process. Including imports in the production function is mainly justified from the fact that international trade exerts an influence on the mechanism of aggregate convergence through the transmission of technological knowledge and increased competition. Estimating the production function using panel data, a Country-Specific Productivity Index (CSPI) has been developed which measures productivity for each country and for each year. This allows for differences in managerial ability, technical differences in production across countries, and country-specific efficiency changes.

To examine productivity convergence cluster analysis has been used to identify groups of EU countries that are likely to obey a common dynamic model. This analysis revealed that EU members can be distinguished in two groups. The first group includes the UK, Belgium, Netherlands, Spain, Portugal, Germany, France and Ireland while the second group contains Sweden, Denmark, Finland, Norway, Greece, Austria, and Italy. The methodology of cointegration developed by Johansen [1988] was used to test for convergence within groups as well as between groups. The hypothesis of convergence could not be accepted. To test further the hypothesis of convergence, whether or not conditional convergence holds was examined. One of the main preconditions in the Maastricht Treaty to move to EMU is inflation performance. For that reason, inflation was included in vector error correction models. The empirical findings suggest that groups are not converging conditionally on inflation. However, it is found that conditionally on inflation, the number of common stochastic long-run trends decreases significantly in comparison with the unconditional case. Therefore, it can be concluded that the inflation objective of the Maastricht Treaty builds a base for decreasing (although not totally eliminating) productivity gaps in the EU.

APPENDIX A: DATA

The European Union's Annual Macro Economic Data Base DG2 data base (AMECO) provides statistical data for all the economies we are interested in, with a high degree of comparability and reliability, from 1960 to 1997. Since output (Y_{rt}) is expressed as final sales, imports of consumption and consumption goods must be added to gross domestic product (GDP) and non-factor costs must be excluded [Apostolakis, 1984]:

$$Y = GDP + M - T_{ind} + S$$

where T_{ind} is indirect taxes, S is subsidies and M is value of imports. All information needed for the right-hand side of equation (A-1) is provided by AMECO for the entire period. All data are expressed at constant market prices in mrd ECU base year.

Employment (L_{rt}) was measured as the number of wage and salary earners and self-employed. The source is AMECO.

Capital (K_{rt}) was measured as the value of net capital stock. The use of net capital stock is preferable to gross fixed investments under the assumption that both series contain the same components (producer durable goods, non-residential construction and other construction) because past discounted streams of investment are included in the former. All data are expressed in constant market prices in mrd ECU base year. The source of data is, again, AMECO.

The price variable is measured by the chain-weighted price deflator of gross domestic product at market prices.

APPENDIX B: MONTE CARLO EXPERIMENT

To analyze the behavior of cointegration - convergence tests, the following data generating process will be considered:

$$x_{1t} = x_{1t-1} + \varepsilon_t \text{ and}$$
$$x_{2t} = x_{1t} + \lambda^t + u_t, \quad t = 1,2,\ldots,T$$

with $\lambda \in (0,1)$ and u_t, ε_t are standard zero — mean white noise processes. The sample size is $T = 40$. The values $\lambda = 0.3$, 0.7 and 0.9 will be considered. For each of $N = 5{,}000$ artificial samples, Johansen's likelihood ratio test has been computed. The results are shown in the Table 12. The distributions of maximum eigenvalue statistic turn out to be essentially symmetric. From the above table, it can be observed that the finite sample distribution of the statistic is invariant to the value of λ. The asymptotic critical value of the maximum eigenvalue test statistic [Hamilton, 1994, table B10] is 3.962. When only a constant is included in the VAR, the Monte Carlo value of the statistic (3.34) is too close to the asymptotic value. Therefore, in about half the samples Johansen's test would indicate the existence of one cointegrating vector. In the other half, the test would indicate that there is no cointegration, and thus no convergence.

TABLE 12
Statistics of the Finite Sample Distribution of Johansen's Likelihood Ratio Test

	λ=0.3	λ=0.7	λ=0.9
	Only constant in VAR		
Mean	3.34	3.39	3.34
95 percent quantile	8.73	8.56	8.52
	Constant and trend in VAR		
Mean	5.54	5.54	5.57
95 percent quantile	11.67	11.41	11.57

Johansen's likelihood ratio statistic is the maximum eigenvalue statistic for testing the null hypothesis of one cointegrating vector against the alternative of no cointegration. The statistics given are based on a Monte Carlo experiment with 5,000 replications. The sample size is T=40.

NOTES

The author would like to thank three anonymous referees , and the editor of this *Journal* for many useful comments which helped to improve the paper in essential ways. Thanks are also due to Panagiotis Reppas for discussions and comments on an earlier version of the paper. Monte Carlo computations were facilitated by the use of the GAUSS program "mgjoh.g" written by Michele Gambera and Kristen Strellec. All remaining errors are the author's responsibility.

1. The idea that imports can be treated as a factor of production was discussed for the first time by Chenery and Strout [1966]. In this seminal study, they emphasized that "the inflow of external resources have become virtually a *separable* factor of production whose productivity and allocation provide one of the central problems for a modern theory of development." This thesis has been adopted, by (among others) Burgess [1974], Apostolakis [1984], Bruno and Sachs [1985], and Aw and Roberts [1985].
2. Nominal convergence refers to convergence of Maastricht indicators, like the rate of inflation, budgetary figures, etc. Real convergence refers to convergence in growth of real output per worker or some productivity measure.
3. The assumption of homogeneity of production function parameters across parameters is critical. However, based on the available data it is the only available empirical route. This assumption is used widely in international studies of convergence (See for example Islam [1995].)
4. One issue that arises in such estimation is whether the individual effects are to be thought of as "fixed" or "random". In the later case the set of regressors is assumed to be independent of the individual effects. In our case estimators relying on such assumptions are not suitable because it is exactly the fact of correlation that forms the basis of our justification for the case data approach [Islam,1995]. In other words, we do not have to assume that regressors and individual effects are independent. It is also assumed (as in Islam [1995] and other studies) that factor inputs and productivity shocks (residuals) are uncorrelated. To make the approach more general in nature, an instrumental variables estimator could be used. We would, of course, have to verify that the variables being used as instruments are indeed instrumental variables. The empirical results would depend on the set of instrumental variables used.
5. It should be noticed that productivity measures depend not only on fixed effects, but also on time effects as well as estimated residuals. See the definition of CSPI in equation (2).
6. This argument was suggested by an anonymous referee.
7. Groups could be defined corresponding to convergence of nominal variables. This idea was suggested by an anonymous referee. The procedure used here gives convergence an unfairly good chance. As will be seen, overall convergence is still rejected. Therefore, rejection of convergence based on this particular method of grouping countries appears to be particularly strong.
8. An anonymous referee has suggested that trade densities may be greater on average between countries within groups than between countries across groups. Although the data do not seem to support this conclusion, the idea that international trade variables may have something to do with the way countries cluster into groups is interesting but beyond the scope of the present paper. It is, however, a very interesting subject of future research.
9. In particular, other things being equal, the within-group tests are less likely to reject convergence than those for randomly chosen groups of countries as group membership is defined by similarity in country behavior. Similarly, the between-group tests are more likely to reject convergence. This argument was suggested by an anonymous referee.
10. For the structure and the sources of the data see Appendix B.
11. The introduction of an I(*1*) variable in a VAR may reduce the number of common trends by more than one when the initial VAR is misspecified. For a correctly specified VAR, the maximum possible change is, of course, one. For example, with 5 variables (instead of 6, because the sixth variable has been incorrectly omitted) we may find 2 cointegrating vectors, (i.e., 3 common trends). With 6 variables and a single cointegrating vector, we would have 5 common trends.

REFERENCES

Apostolakis, B. E. Substitution between Imports and Primary Inputs in the Netherlands 1953-1977. *Eastern Economic Journal*, Spring 1984, 149-60.

Aw, B. Y. and Roberts, M. The Role of Imports from the Newly Industrialising Countries in U.S. Production. *Review of Economics and Statistics*, February 1985, 108-17.

Baltagi, H. B. Griffin, J. M. and Rich P. D. The Measurement of Firm-Specific Indexes of Technical Change. *Review of Economics and Statistics*, November 1995, 654-63.

Barro, R. J. and Sala-i-Martin, X. Convergence across States and Regions. Brookings Papers on Economic Activity, March 1991, 107-58.

__________. Convergence. *Journal of Political Economy*, November 1992, 223-51.

Baumol, W. J. Productivity Growth, Convergence and Welfare: What the Long-Run Data Show. *American Economic Review*, December 1988, 1072-85.

Ben-David, D. Equalising exchange: Trade liberalisation and income convergence. Quarterly Journal of Economics, August 1993, 653-79.

Bernard, A. and Jones, I. C. Productivity across industries and countries: Time series theory and evidence. Review of Economics and Statistics, February 1996a, 135-46.

__________. Technology and convergence. Economic Journal, March 1996b, 1037-44.

__________. Interpreting tests of the convergence hypothesis. Journal of Econometrics, March 1996, 161-73.

Bernard, A. and Durlauf, N. S. Convergence in international output. *Journal of Applied Econometrics*, April-June 1995, 97-108.

Bruno, M. and Sachs, J. *Economics of World-Wide Stagflation*, Cambridge: Harvard University Press, 1985.

Burgess, F. D. A Cost Minimization Approach to Import Demand Equations. *Review of Economics and Statistics*, May 1974, 225-34.

Canova, F. and Marcet, A. The Poor Stay Poor: Non-convergence across Countries and Regions. Paper presented at CEPR Workshop on Empirical Macroeconomics, 1995.

Cass, D. Optimum Growth in an Aggregate Model of Capital Accumulation. *Review of Economics and Statistics*, March 1965, 233-40.

Chenery, H. and Strout A. Foreign Assistance and Economic Development. *American Economic Review*, October 1966, 679-733.

Crafts, N. Productivity Growth Reconsidered, *Economic Policy*, October 1992, 387-426.

Denny, M. and May, D. The Existence of a Real Value Added Function in the Canadian Manufacturing Sector. *Journal of Econometrics*, January 1977, 55-69.

Dickey, D. A and Fuller, W. A. Likelihood Ratio Statistics for Autoregressive Time Series with a Unit Root. *Econometrica*, June 1981, 1057-72.

Dollar, D., Wolf, N. E. and Baumol, J. W. The Factor-price Equalisation Model and Industry Labor Productivity: An Empirical Test across Countries, in *Empirical Methods for International Trade*, edited by R. Feenestra. Cambridge: MIT Press, 1988, 23-47.

Doornik, J. A. and Hendry, D. F. PcFiml 8.0. *Interactive Econometric Modelling of Dynamic Systems*. Institute of Economics and Statistics, Oxford: Oxford University Press, 1994.

Dowrick, S. and Nguyen D. T. OECD Comparative Economic Growth 1950-1985: Catch Up and Convergence. *American Economic Review*, December 1989, 1010-30.

Durlauf, S. N. and Johnson, P. A. Multiple Regimes and Cross-country Growth Behaviour. *Journal of Applied Econometrics*, October-December 1995, 365-84.

Engle, R. F. and Granger, C. W. J. Cointegration and error correction: Representation. estimation and testing. Econometrica, June 1987, 251-76.

Engle, R. F. Autoregressive Conditional Heteroscedasticity: With Estimates of the Variance of United Kingdom Inflation. *Econometrica*, July 1982, 987-1007.

Evans, P. and Karras, G. Do Economies Converge? Evidence from a Panel of U.S. States. *Review of Economics and Statistics*, August 1996, 384-88.

Godfrey, L. G. *Misspecification Tests in Econometrics*. Cambridge: Cambridge University Press, 1988.

Gordon, J. R. Discussion, in Productivity Growth Reconsidered by N. Crafts, *Economic Policy*, October 1992, 414-21.

Griliches, Z. and Ringstad, V. Economies of Scale and the Form of the Production Function: An Econometric Study of Norwegian Establishment Data. Amsterdam: North-Holland, 1971.

Hamilton, J. D. *Time Series Analysis*. Princeton: Princeton University Press, 1994.

Hobijn, B. and Franses, P. H. Asymptotically Perfect and Relative Convergence of Productivity. Mimeo, Department of Economics, New York University, 1998.

Islam, N. Growth Empirics: A Panel Data Approach. *Quarterly Journal of Economics*, November 1995, 1127-70.

Jaret, P. I. and Selody G. J. The Productivity – Inflation Nexus in Canada. *Review of Economics and Statistics*, August 1982, 361-67.

Johansen, S. Statistical analysis of cointegration vectors. Journal of Economic Dynamics and Control, June/September 1988, 231-54.

Johansen, S. and Juselius, K. Maximum Likelihood Estimation and Inference on Cointegration - With Application to the Demand for Money. Oxford Bulletin of Economics and Statistics, May 1990, 169-210.

Kelejian, H. H. An Extension of a Standard Test for Heteroscedasticity to a Systems Framework. *Journal of Econometrics*, November 1982, 325-33.

Kwiatkowski, D., Phillips, P. C. B., Schmidt, P. and Shin, Y. Testing the Null Hypothesis of Stationarity Against the Alternative of a Unit Root: How Sure Are We that Economic Time Series Have a Unit Root? *Journal of Econometrics*, October/December 1992, 159-78

Lee, K., Pesaran, M. H. and Smith, R. Growth and Convergence in a Multi-country Empirical Stochastic Solow Model. *Journal of Applied Econometrics*, July/August 1997, 357-92.

Lutkepohl, H. Introduction to Multiple Time Series Analysis, New York: Springer-Verlag, 1991.

Mankiw, N. G., Romer, D. and Weil, N. D. A Contribution to the Empirics of Economic Growth. *Quarterly Journal of Economics*, May 1992, 407-38.

Perron, P. The Great Crash, the Oil Price Shock, and the Unit Root Hypothesis. *Econometrica*, December 1989, 1361-1401.

Quah, T. D. Empirics for Economic Growth and Convergence. *European Economic Review*, June 1996a, 1353-1357.

__________. Twin Peaks: Growth and Convergence in Models of Distribution Dynamics. *Economic Journal*, July 1996b, 1045-1055.

Reimers, H. E. Comparison of Tests for Multivariate Cointegration. *Statistical Papers*, June 1992, 335-359.

Riezman, R. G., Tamura, R. and Whiteman, C. H. The Case for Convergence. Proceedings of the Business and Economic Statistics Section, American Statistical Association, June 1993, 59-67.

Sala-i-Martin, X. Regional cohesion: Evidence and theories of regional growth and convergence. *European Economic Review*, June 1996, 1325-1352.

Solow, R. M. A Contribution to the Theory of Economic Growth. *Quarterly Journal of Economics*, March 1956, 65-94.

Tsionas, E. G. *Regional Growth and Convergence: Evidence from the United States*. Regional Studies 1999a, forthcoming.

__________. Inflation and Productivity: Empirical evidence from Europe. *Review of International Economics*, forthcoming.