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# CONVERGENCE IN INTERNATIONAL OUTPUT: DEFINITIONS, TESTING METHODOLOGIES AND EMPIRICAL EVIDENCE

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# 1. INTRODUCTION

The current large differences in per capita income across countries and regions have enormous welfare implications. Differences in per capita income across countries and regions account for the levels of poverty and disparity in the distribution of the world wealth. Thus, an important economic issue of vital importance for human welfare is whether poor countries or regions tend to converge toward rich ones. Many scientists have carried out researches regarding the existence or not of automatic forces that lead to convergence over time in the levels of per capita income and product. To the extent that convergence occurs, it suggests that, at least over long time horizons, world inequality will diminish.

Due to many economic, political and institutional changes European community is of particular interest to many researchers. The Exchange Rate Mechanism in 1979, the opening of Common Market in 1993, the introduction of the Euro in 2001 and the worldwide increase in trade and financial flows have contributed to a closer synchronization of economic fluctuations across European countries. Every country-member of the European Union has the obligation to adjust its policies so as they satisfy the Maastricht and Copenhagen criteria and are in accordance with the aims that European Union sets. It is a logical necessity that the countries-members of the European Union have common economic and institutional structure and their nominal and real variables tend to evolve more closely over time.

The greater the degree of real convergence is, the smoother the future running of the enlarged European Union will be. When less money in the form of subsidies is transferred from the rich countries and regions to the poor ones, more money will be available for structural adjustments to help harmonization of business cycles. The ultimate benchmark for measuring convergence is the convergence in levels of real per capita income, real per capita Gross Domestic Product. When output per person (or GDP per capita) is high, people have more goods and services, and this may increase societal well-being. Thus, one of the major policies of European Union is the decrease of real per capita GDP divergence between its members in order to ensure welfare and symmetrical growth to all European citizens. The elimination of economic disparities is a prerequisite for continuous strengthening of European Union and the attraction of more countries in E.U.

The aim of the present research is to investigate whether there is convergence in per capita GDP among different countries in a global context. Special emphasis is laid on the 15 state members of E.U., after their effort for convergence, signing the Maastricht convention in 1992 and till 2004. We present some stylized facts and the prevalent definitions of convergence. Further, we present the various testing methodologies of convergence and we critically evaluate their empirical findings. We, then, propose a pair-wise approach to testing for output and growth convergence and present its conclusions.

The investigation of the degree of convergence in real per capita output in selected group of countries was prompted by two reasons. First, evidence of no economic convergence within a region can bring about social and political instability as economic performance varies significantly across countries. Second, evidence of no convergence in unions such as European Union would imply that association agreements and other institutional linkages with respect to the particular union do not necessarily lead to economic convergence. Ultimately, if there is no automatic mechanism that ensures the convergence of economies over time, it is not only justified but also probably ethically necessary and "politically correct" to implement public policies aimed at helping the poorer (regions or countries) to catch-up as fast as possible with the richer. Knowing whether it is justified to dedicate public funds to these policies is therefore an important matter both for national and supra-national governments.

## 2. STYLIZED FACTS

A first set of stylized facts relates to the world population distribution. Most of the world's economies are small. Over the period 1960-4, the largest 5% of the world's economies contained 59,0% of the world's population. The largest 10% contained 70,9%. 25 years later, over the period 1985-9, the largest 5% of the world's economies held 58,3% of the world's population. The largest 10% held 70,2%. In both periods, the lower 50% of the world's economies ranked by population held in total less than 12,5% of the world's population.

A second set of facts relates to the stability of these cross-country population distributions. Over the period 1960-89, the percentiles associated with the distribution of population across countries have been remarkably stable. This is not to say that those countries now highly populated have always been highly populated, rather that the distribution of cross-section differences has changed little.

In contrast to the stability of population size distributions, the cross-country distributions of per capita incomes seem quite volatile. From 1960 through 1989, world income per capita grew at an annual average rate of 2,25%. However, the time paths of per capita incomes in individual economies varied widely around that of the world average. Averaged over 1960-4, the poorest 10% of the world's national economies (in per capita incomes, taken at the beginning of the interval) each had per capita incomes less than 0,22 times the world average.

Those economies contained 26,0% of the world's population. Poor economies therefore appear to be also large ones, although it is actually China alone accounting for most of that population figure. By contrast, the richest 10% of national economies each had per capita incomes exceeding 2,7 times the world average, while all together containing 12,5% of the world's population. By 1985-9 the 10th percentile per capita income level had declined to only 0,15 times the world average – those economies in that poorest 10% then held only 3,3% of the world's population as China became relatively richer and became no longer a member of this group. At the same time the 90th percentile per capita income level increased to 3,08 times the world average. The share of the world population in those 10% richest economies fell to 9,3%.

Ultimately, the extremes appear to be diverging away from each other – with the poor becoming poorer, and the rich richer. However, that is not the entire picture. In 1960-4, the income distance between the 15th and 25th percentiles was 0,13 times world per capita income. By 1985-9, this distance had fallen to 0,06. Over this same time period, the income distance between the 85th and 95th percentiles fell from 0,98 times world per capita income to 0,59. Thus, while the overall spread of incomes across countries increased over this 25 year period, that rise was far from uniform. Within clusters, one sees instead a fall in the spread between (relatively) rich and (relatively) poor.

The evidence also suggests that growth miracles are occurring more frequently than growth disasters, and that the relative frequency of miracles has increased. Hong Kong, Singapore, Japan, Korea, and Taiwan all stand out as growth miracles, having increased their relative incomes substantially. For example, Hong Kong, Singapore, and Japan grew from about 20% of U.S. GDP per worker in 1960 to around 60% in 1988. Korea rose from 11% to 38%. Several less well-known growth miracles are also noteworthy. Relative income in Botswana increased from 5% to 20%, in Romania from 3% to 12%, and in Lesotho from 2% to 6%. A large number of the growth disasters – countries that experienced large declines in relative income – are located in sub-Saharan Africa. For example, Chad fell from a relative income of 8% to 3%. However, growth disasters outside Africa are also impressive. For example, Venezuela was the third richest economy in the world in 1960 with an income equal to 84% of U.S. income. By 1988, relative income had fallen to only 55%.

# 3. <u>GROWTH ACCOUNTING</u>

In this section, we quote the main sources of growth. Output grows through increases in inputs and through increases in productivity due to improved technology and a more able workforce. The production function provides a quantitative link between inputs and outputs.

$$\mathbf{Y = A * F ( K , N )} \qquad \mathbf{(1)}$$

$$\mathbf{\Delta Y/Y = [ (MPN*N) / Y ] * \Delta N/N + [ (MPK*K) / Y ] * \Delta K/K + \Delta A/A} \qquad \mathbf{(2)}$$

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Output = | Labor | * | Labor | + | Capital | * | Capital | + Technical |
| Growth | Share | | Growth | | Share | | Growth | Progress |

$$\mathbf{\Delta(Y/N) / (Y/N) = [ (MPK*K) / Y ] * \Delta(K/N) / (K/N) + \Delta A/A} \qquad \mathbf{(3)}$$

Equation (1) shows that more input means more output. In other words, the marginal product of labor (MPN) and the marginal product of capital (MPK) are both positive. Equation (2) is a transformation of equation (1) and summarizes the contributions of input growth and of improved productivity to the growth of output. Equation (2) states that (i) labor and capital each contribute an amount equal to their individual growth rates multiplied by the share of that input in income and (ii) the growth rate of total factor productivity is the amount by which output would increase as a result of improvements in methods of production, with all inputs unchanged. Equation (3) accounts for growth in per capita output. The term K/N is called capital-labor ratio and is a key determinant of the amount of output a worker can produce. Ultimately, some conclusions that can be derived from the above equations are the following: The important determinants of GDP growth are technical progress, increased labor supply and capital accumulation. The important determinants of growth in GDP per capita are technical progress and capital accumulation. Increased population actually decreases GDP per capita even though it increases GDP. In other words, more workers means more output, but if the number of workers is increased without proportionately increasing the number of machines, the average worker will be less productive because he has less equipment to work with.

However, in specific times and in specific places inputs other than labor and capital matter a great deal. Two other important inputs are natural resources and human capital. Natural resources include the nation’s abundant, fertile land and the discovery or development of massive oil reserves. Furthermore, investment in human capital through schooling, on-the-job training, and other means in the same way that physical investment leads to increased physical capital. Adding human capital, H, the production function can be written as ***Y= A * F ( K, H, N )***. Immigration boosts per capita output when skilled workers enter the country, a fact that has frequently benefited the United States. In contrast, immigration consisting of war refugees typically depresses per capita output in the short run. However, a factor of production adds to output growth only so long as the supply of the factor itself is growing. Such fluctuations in factor input may last for several years, but they rarely last for several decades. Over great sweeps of history the two important factors are capital accumulation (physical and human) and technological progress.

## 4. THE NEOCLASSICAL MODEL

In this section, we analyze the neoclassical theory of growth convergence and attempt to build some connections between the theoretical formulations and observed empirical regularities.

The neoclassical growth model, originating with Solow, has profoundly affected the way in which economists conceptualize long run interrelationships between economies in the long run. By ascribing economic growth to the joint impact of exogenous technical change and capital deepening on an economy with concave short run production opportunities, the neoclassical model makes very strong predictions with respect to the behavior of economies over time. In particular, given a microeconomic specification of technologies and preferences, per capita output in an economy will converge to the same level regardless of initial capital endowments. In comparing different economies, this means that differences in per capita output for economies with identical technologies and preferences will be transitory.

The key empirical implications of the neoclassical model depend solely on the assumed production function. The production function in the neoclassical theory of growth, assuming labor augmented technological progress, is

$$\mathbf{Y = F(K, NHA)}$$

where Y is total output, N is the quantity of labor input, H is the stock of human capital, A is the state of technology, K is physical capital. F is assumed to be increasing, homogenous, and concave. We assume that the stock of human capital H is embodied in the labor force so that the effective labor unit is $\tilde{N}$ = NH. Thus, the production function takes the form

$$Y = F(K, \tilde{N} A)$$

Moreover, we define quantities in per effective labor unit terms as

$$\tilde{y} = Y/\tilde{N}A \text{ and } \tilde{k} = K/\tilde{N}A$$

These are unobservable, however, and so we write their measured counterparts as

$$y = HA * \tilde{y} = Y/N \quad \text{and} \quad k = HA * \tilde{k} = K/N$$

The definitions imply y = F(k, HA). In turn, total output can be rewritten:

Y = $\tilde{N}$ A * F(($\tilde{N}$ A)$^{-1}$ K, 1) $\Rightarrow$ $\boxed{\tilde{y} = \mathbf{f}(\tilde{k})}$ (4), where f(•) = F(•,1)

Further, the neoclassical model makes the following assumptions:

1) ΔH = 0, normalizing H(0) = 1
2) ΔA = ξ ≥ 0, given A(0) > 0
3) ΔN = v ≥ 0, given N(0) > 0
4) K scalar, given K(0) > 0

The aforementioned assumptions suggest that only physical capital is accumulated, and population growth and technical change are exogenous. In addition, we assume that

$$\forall\ \tilde{N}A > 0 : \lim_{K \to \infty} F(K, \tilde{N}A)/K = 0 \quad (5)$$

Physical capital is assumed to depreciate exponentially at rate δ > 0 and we suppose that savings is a constant fraction τ∈(0,1) of income. Therefore, the investment required to maintain a given level, $\tilde{k}$, of capital per capita depends on population growth, the depreciation rate and the technological change. In other words, an economy needs investment v$\tilde{k}$ to provide capital for new workers, investment δ$\tilde{k}$ due to "loss" of capital because of the depreciation and investment ξ$\tilde{k}$ due to technological improvement. Thus, capital accumulation will be

$$\boxed{\Delta\tilde{k}/\tilde{k} = t * f(\tilde{k})/\tilde{k} - (\delta + v + \xi)} \quad (6)$$

It follows that when saving, τf($\tilde{k}$), exceeds the investment required to maintain a given level, $\tilde{k}$, of capital per capita, then $\tilde{k}$ is increasing, as specified by equation (6).

From this formulation it arises the following question: does a steady-state equilibrium always exist for an economy? As steady-state equilibrium of an economy, we define the combination of per capita GDP and per capita capital where the economy will remain at rest, that is, where per capita economic variables are no longer changing, Δ$\tilde{y}$=0 and Δ$\tilde{k}$=0. The steady-state values of per capita income and capital, denoted y* and k*, are those values where the investment required to maintain a given level, $\tilde{k}$, of capital per capita is just equal to the saving generated by the economy. If saving is greater than this investment requirement, then capital per worker rises over time and therefore output does as well. If saving is less than this investment requirement, then capital and output per worker fall. The steady-state values y* and k* are the levels of output and capital at which saving and required investment balance.

Figure 1 shows that a unique steady-state equilibrium exists and that $\tilde{k}$ satisfying equation (6) is dynamically stable everywhere in the region $\tilde{k}$ > 0. Function f($\tilde{k}$)$\tilde{k}^{-1}$ is continuous and tends to infinity as $\tilde{k}$ tends to zero and it tends to zero as $\tilde{k}$ tends to infinity. Moreover, it is guaranteed to be monotone strictly decreasing. The vertical distance between f($\tilde{k}$)$\tilde{k}^{-1}$ and (δ + v + ξ)τ$^{-1}$ is τ$^{-1}\Delta\tilde{k}/\tilde{k}$. Convergence to steady state $\tilde{k}$* therefore occurs for all initial values $\tilde{k}$. Since $\tilde{y}$ = f($\tilde{k}$), we immediately have that output per effective worker too has a unique, globally stable steady state.

The dynamics of the neoclassical model can be understood further by taking a Taylor series expansion in $\log\tilde{k}$ about steady-state $\tilde{k}^*$,

$$\Delta\tilde{k}/\tilde{k} = \tau\,\{\nabla f(\tilde{k}) - f(\tilde{k})\tilde{k}^{-1}\}\big|_{k=k^*} \times (\log\tilde{k} - \log\tilde{k}^*)$$

For F Cobb-Douglas,

$Y = F(K, \tilde{N}A) = K^{\alpha}(\tilde{N}A)^{1-\alpha}$ , $\alpha \in (0,1)$

$\Rightarrow f(\tilde{k}) = \tilde{k}^{\alpha}$ (7)

this first-order series expansion becomes

$\frac{d}{dt}\log\tilde{k} = -(1-\alpha)(\delta + v + \xi) \times (\log\tilde{k} - \log\tilde{k}^*)$

$= \lambda \times (\log\tilde{k} - \log\tilde{k}^*)$

where we define as speed of convergence **$\lambda = -(1-\alpha)(\delta + v + \xi) < 0$** (8)

Solving this differential equation gives:

$\log\tilde{k}(t) - \log\tilde{k}^* = (\log\tilde{k}(0) - \log\tilde{k}^*)e^{\lambda t}$

$\Rightarrow \log\tilde{y}(t) - \log\tilde{y}^* = (\log\tilde{y}(0) - \log\tilde{y}^*)e^{\lambda t} \to 0$ as $t \to \infty$ (9)

i.e., $\log\tilde{k}$ and $\log\tilde{y}$ converge to their respective steady state values $\log\tilde{k}^*$ and $\log\tilde{y}^* = \log f(\tilde{k}^*)$ exponentially at rate $|\lambda|$. The farther the actual values of $\log\tilde{k}$ (and thus $\log\tilde{y}$) are from their steady-state values, $\log\tilde{k}^*$ (and thus $\log\tilde{y}^*$), the faster an economy will grow. In other words, the speed of convergence is inversely correlated with the distance between the actual and steady-state values. As α increases to 1 this rate of convergence approaches 0: thus, the larger is the Cobb-Douglas coefficient on physical capital, the slower does $\log\tilde{y}$ converge to its steady state value.

Combining the accumulation equation (6) and the Cobb-Douglas assumption (7), we observe from Figure 1 that the steady state level is:

$$\tilde{y}^* = (\tilde{k}^*)^{\alpha} = [(\tilde{k}^*)^{-(1-\alpha)}]^{-\alpha/(1-\alpha)} = [(\delta + v + \xi)^{-1}\tau]^{\alpha/(1-\alpha)} \quad (10)$$

Equation (10) gives steady state income levels as depending positively on the saving rate and negatively on the labor force growth rate.

From observed per capita income $y = \tilde{y}HA = \tilde{y}A$ we have:

$\log y(t) = \log\tilde{y}(t) + \log A(t)$

$= \log\tilde{y}^* + [\log\tilde{y}(0) - \log\tilde{y}^*]e^{\lambda t} + \log A(0) + \xi t$

Moreover, since $\tilde{y}^* = f(\tilde{k}^*)$ and $f(\tilde{k}^*)/\tilde{k}^* = (\delta + v + \xi)\tau^{-1}$, there is some function g such that $\tilde{y}^* = g((\delta + v + \xi)^{-1}\tau)$. We can therefore write the implied sample path in observable per capita income as

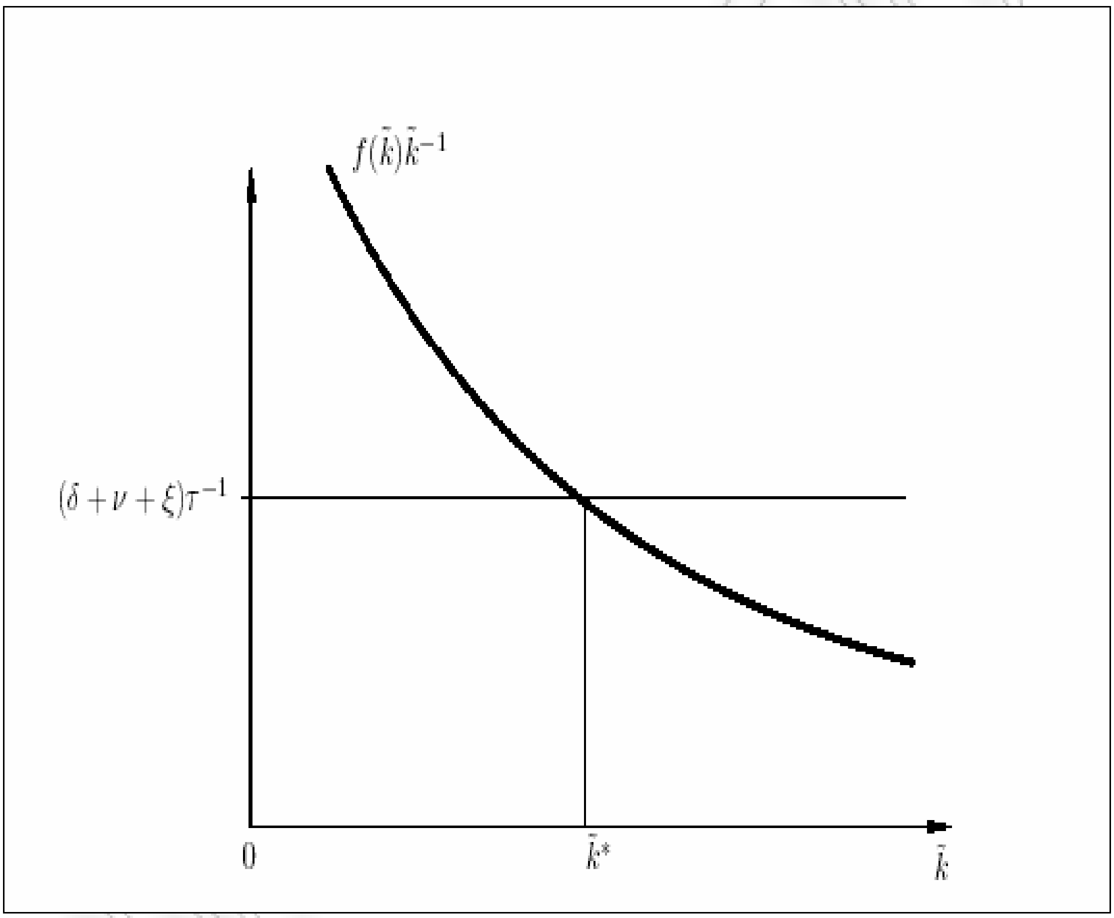
$$\log y(t) = \log(y((\delta + v + \xi)^{-1}\tau)) + \log A(0) + \xi t + [\log y(0) - (\log(g((\delta + v + \xi)^{-1}\tau)) + \log A(0))]e^{\lambda t} \quad (11)$$

and its time derivative

$$\frac{d}{dt}\log y(t) = \xi + \lambda \times [\log y(0) - (\log(g((\delta + v + \xi)^{-1}\tau)) + \log A(0))]e^{\lambda t} \quad (11')$$

We can divide $\log y$ from equation (11) as having two components: first, the term involving $e^{\lambda t}$, namely the convergence component and second, the rest of the right-hand side, namely the levels component. When the term in $e^{\lambda t}$ approaches its limiting value, then the first component of the equation (11) can be viewed as explaining the steady-state cross section distribution of income. On the other hand, when the term in $e^{\lambda t}$ is taken to be central – and the rest of the right-hand side of equation (11) is given (or are taken to be nuisance parameters) – the equation can be viewed to explaining the process of convergence in income.

**Figure 1**

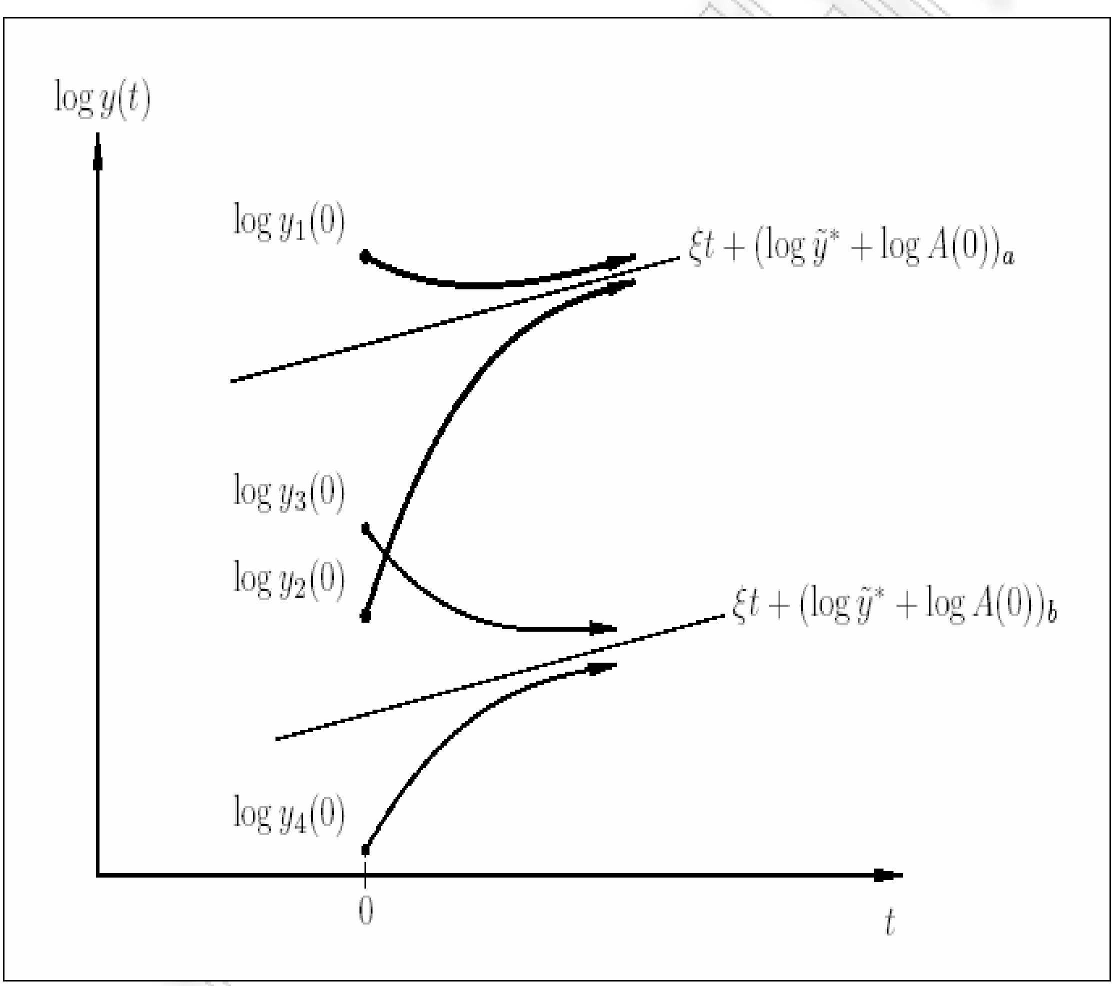



Equation (11) is depicted in Figure 2 for two possible values of $\log(g((\delta + v + \xi)^{-1}\tau)) + \log A(0)$. The figure shows two different possible steady state paths – corresponding to two possible values for the sum $\log \tilde{y}^* + \log A(0) = \log(g((\delta + v + \xi)^{-1}\tau)) + \log A(0)$. As long as $\log \tilde{y}^* + \log A(0)$ remains unobserved or unrestricted, any pattern of cross-country growth and convergence is consistent with the model. As drawn in Figure 2, the a value applies to economies at $y_1(0)$ and $y_2(0)$ while the b value to $y_3(0)$ and $y_4(0)$. Economies 1 and 2 converge towards each other, as do economies 3 and 4. At the same time, however, economies

2 and 3, although each obeying the neoclassical growth model, are seen to approach one another, criss-cross, and then diverge.

Equation (11') decomposes the growth rate of per capita income in country i into two distinct components. The first component, ξ, measures growth due to technological progress (which is assumed to be constant across countries in the neoclassical model), whereas the rest of the right-hand side measures growth due to the gap between initial per capita output and steady-state value. This second source of growth is what is meant by "catching up" in the literature. As $t \rightarrow \infty$ the importance of the catch-up term, which reflects the role of initial conditions, diminishes to zero.

**Figure 2**




Under the assumptions that the rates of technological progress and the speed of convergence parameters are constant across countries, the important empirical implications of equation (11) is that, in a cross-section of countries, we should observe a negative relationship between average rates of growth and initial levels of output over any time period – countries that start out below their balanced growth path must grow relatively quickly if they are to catch up with other countries that have the same levels of steady-state output per capita and initial efficiency. This is closely related to the hypothesis of conditional convergence, which is often understood to mean that countries converge to parallel growth paths, the levels of which are assumed to be a function of a small set of variables. However, a negative coefficient on initial income in a cross-country growth regression does not automatically imply conditional convergence in this sense, because countries might instead simply be moving toward their own different steady-state growth paths.

## 5. CROSS-COUNTRY GROWTH REGRESSIONS

Many cross-country regression studies have attempted to extend the context of neoclassical model by adding additional control variables $Z_i$ to the regression suggested by (11) and (11'). Such studies may be understood as allowing for predictable heterogeneity in the steady-state growth term $\xi_i$ and initial technology term $A_{i,0}$ that are assumed constant across i in (11) and (11').

Control variables $Z_i$ can not be identified whether they are correlated with steady-state growth $\xi_i$ or the initial technology term $A_{i,0}$. For this reason, proponents of a common steady-state growth rate will not be dissuaded by the finding that particular choices of $Z_i$ help predict growth beyond the Solow regressors. Nevertheless, it seems plausible that the control variables $Z_i$ may sometimes function as proxies for predicting differences in efficiency growth $\xi_i$ rather than in the initial technology $A_{i,0}$. As argued in Temple (1999), even if all countries have the same total factor productivity (TFP) in the long run, over a twenty- or thirty-year sample the assumption of equal TFP growth is highly implausible, so the variables in $Z_i$ can explain these differences.

The canonical cross-country growth regression is represented by

$$g_i = b \log y_{i,0} + \psi X_i + \pi Z_i + e_i \qquad (12)$$

where $g_i$ is the average growth rate of economy i over the sample period, $y_{i,0}$ is the log of per capita output in the first year of the sample period, $e_i$ is a random error term and $X_i$ contains a constant, log($v_i$ + ξ + δ) and log $\tau_i$. We can decompose equation (12) into two distinct growth determinants components. To be exact, the growth determinants that are suggested by the Solow growth model is represented by the variables log $y_{i,0}$ and $X_i$. On the contrary, the growth determinants that are represented by $Z_i$ are those that lie outside Solow's original theory.

The distinction between the Solow variables and $Z_i$ is important in understanding the empirical literature. While the Solow variables usually appear in different empirical studies, reflecting the treatment of the Solow model as a baseline for growth analysis, choices concerning which $Z_i$ variables to include, vary greatly.

## 6. DIFFUSION OF TECHNOLOGY AS A MAIN SOURCE OF CONVERGENCE

The main contention of the "convergence hypothesis" states that under certain conditions, being behind gives a productivity laggard the ability to grow faster than the early leader. Abramovitz (1986) popularized and elaborated on the idea that being technologically backward carries an opportunity for faster growth. According to Abramovitz, when a leader discards old stock and replaces it, the accompanying productivity increase is governed and limited by the advance of knowledge between the time when old capital was installed and the time it was replaced. Those who are behind, however, have the potential to make a larger leap. New capital can embody the frontier of knowledge but the capital it replaces was technologically superannuated. So the larger the technological and, therefore, the productivity gap between leader and follower, the stronger the follower's potential for growth in productivity. Other things being equal, the faster one expects the follower's growth rate to be. Followers tend to catch up faster if they are initially more backward.

Abramovitz notes that a necessary condition for catch up is "social capability" in a backward economy. Social capability refers to adequate entrepreneurial ability, managerial and technical staff, and ancillary institutions (banks, insurance companies, effective and impartial judiciary, etc.). Moreover, social capability entails cultural traits and attitudes towards work and wealth, class mobility within a social structure, and the ability to form a corporation beyond family business. Without social capability technological backwardness will not be advantageous.

Although it can be argued that social capability may emerge or be strengthened in an expanding economy, historical evidence shows that it is primarily exogenous and usually precedes the convergence process. In an analysis of economic development in virtually every region of the world, Maddison (1995) points out that Japan paved the way for rapid economic growth in the 20$^{th}$ century by reforming her institutions in the 19$^{th}$ century. Countries in South America and India that did not reform their institutions, Maddison notes, were unable to take advantage of their backwardness.

Baumol (1986) uses Maddison's data in an analysis of long-run growth and convergence among 16 advanced economies. After establishing convergence, he suggests, in the same vein as Abramovitz, that technology is a public good and its diffusion leads to catch-up and convergence. Growth spills over to the economies that are socially capable of applying new technology. In a later publication, Baumol (1994) calls this approach “contagion”, suggesting that advancement of technology creates an external benefit across economies.

Although multinational corporations provide a most effective vehicle for transfer of technology, not every host economy to the multinational corporations experiences higher growth. Blomström, Lipsery and Zejan (1996) find that only the wealthiest 50% of developing economies, judged by per capita income, enjoy a higher economic growth due to inflows of foreign direct investment. Poor economies deprived of adequate resources are unable to absorb the technology brought in by the multinational corporations.

A follower-economy can experience a faster rate of growth because imitation of technology is less costly than innovation. In developing a new technique, a leader-economy commits errors that an imitator can avoid. A number of studies provide estimates of imitation cost and the time required for a successful imitation. Mansfield, Schwartz, and Wagner (1981) find that in products such as chemicals, electronics, machinery, and drugs in the United States, the imitation cost averages 65% of the innovation cost. Teece (1977) finds that for multinational corporations the cost of technology transfer amounts to 19% of overall cost of operation. The time it takes for imitators to learn about new products is roughly about one year. Mansfield (1985) finds a one year lag for 70% of product innovations. Caballero and Jaffe (1993) estimate that the time it takes for new ideas to influence other researchers is from one to two years.

## 7. HETEROGENEOUS PROGRESS OF TECHNOLOGY AND GROWTH

We assume that the engine of growth is technological progress, implying that output per capita grows in the long run because of the creation of ideas. Ideas diffuse across countries, perhaps not instantaneously, but eventually. For example, Greece does not grow only or even largely because of the ideas created by Greek, but rather a substantial amount of growth in Greek output per capita is attributed to ideas invented elsewhere in the world. In this context, the fact that countries of the world eventually share ideas means that their incomes cannot get infinitely far apart. Rather, all countries eventually grow at the average rate of growth of world knowledge.

Further, one common assumption that we can adopt is that technological progress follows a simple exponential path of the form

$$\boxed{A_{it} = A_{i0}e^{\xi t}} \qquad (13)$$

where the growth rate of technology is common across countries. The latter condition is obviously restrictive and presumes that all economies experience technological improvements at the same rate $\xi_{it} = \xi$ over time, while operating from different initial levels ($A_{i0}$). A more plausible assumption is that the technology growth rates $\xi_{it}$ differ across countries and over time but may possibly converge to the same rate $\xi$ as $t \rightarrow \infty$. In such a case, the evolution of $A_{it}$ is inevitably more complex than (13), thereby accommodating a wider range of possible growth behavior.

Moreover, we can make the additional assumption that technology is a public good which is widely available. Thus, technology can be represented at time t by a common technology variable $C_t$ which is assumed to follow a simple exponential path of the form

$$C_t = C_0 e^{xt} \qquad (14)$$

The full extent of common technology $C_t$ is taken to be instantly accessible to developed countries. Indeed, it may be presumed that these countries created $C_t$ and are materially involved in determining its future time path. Followers, like the developing nations, generally have to learn technology first and develop an infrastructure to absorb and utilize it. As a result, it may be assumed that such countries cannot fully share in the present level of $C_t$. Depending on the speed of learning in these countries and the time form of their exposure to the common technology, the actual technological progress of developing countries is likely to differ across i over time. To model such cross section and temporal heterogeneity, we may treat $C_t$ as a factor of production which different countries share in at their own idiosyncratic rate. More specifically, we set

$$A_{it} = A_{i0} e^{\xi_{it} t} = A(\xi_{it}, t, A_{i0}) \qquad (15)$$

The technological growth rate of economy i is now $\xi_{it}$ + t$\xi_{it}$ and is time dependent. This formulation means that technological learning differs across countries and over time even though there is a common underlying technology. These differences among economies allow for phenomena such as technological catch-up and slow-down, which are known to be important in empirical work.

Using this framework and a Cobb-Douglas technology, the transitional growth path for country i is shown to be:

$$\log y_{it} = \log \tilde{y}_i^* + [\log \tilde{y}_{i0} - \log \tilde{y}_i^*] e^{-\lambda_{it} t} + \log A_{it} \qquad (16)$$

the speed of convergence parameter $\lambda_i$ is functionalized as

$$\lambda_{it} = \lambda(\alpha_i, \delta_i, v_i, \xi_{it} ; t)$$

$$- \quad + \quad + \quad +$$

and appropriate sign effects are indicated beneath these parameters.

One of the most persuasive explanations for why some countries have grown faster than others over long periods of time is transition dynamics. According to the principle of transition dynamics, the further a country is below its steady state position, the faster the country should grow. In particular, this principal emphasizes the importance of technology transfer and the diffusion of ideas. The principle of transitional dynamics stresses that the growth rate of the economy is proportional to the gap between the country's current position and its steady state position, referring to a key parameter known as speed of convergence $\lambda$, which describes the rate at which a country closes the gap between its current and steady state position.

The term involving $e^{-\lambda_{it}t}$ in (16) decays as $t \to \infty$ provided the condition $\lambda_{it}t \to \infty$ holds, in which case the path of log per capita real income is primarily dependent on the term $\xi_{it}t$ and may therefore be substantially affected by heterogeneity in technology progress over time and across economies. Thus, growth convergence requires that log per capita real income be the same across countries in the long run. A necessary condition for this requirement in a model with heterogeneous transitional technology is

$$\xi_{it+k} \to \xi, \quad \text{for all } i \text{ as } k \to \infty \qquad (17)$$

Ultimately, the speed of convergence parameter $\lambda_{it}$ may reasonably be regarded as an increasing function of technological progress $\xi_{it}$. Accordingly, poor economies with a low level of technological accumulation may begin with a low $\lambda_{it}$ and a correspondingly slow speed of convergence. As such countries learn faster (e.g., from improvements in education and the diffusion of technology), their $\xi_{it}$ rises and may exceed the rate of technological creation in rich nations. So, $\lambda_{it}$ rises and the speed of convergence of these economies begins to accelerate. Conversely, if a poor country responds slowly to the diffusion of technology by learning slowly or through suffering a major economic disaster which inhibits its capacity to adopt new technology, its speed of convergence is correspondingly slower in relation to other countries (including rich countries), thereby producing the phenomenon of transitionally divergent behavior in relation to other countries. In other words, heterogeneous neoclassical economic growth may accommodate a family of potential growth paths in which some divergence may be manifest. If over time the speed of learning in the divergent economies becomes faster than the speed of technology creation in convergent rich economies, there is recovery and catch-up. In this event, the inequality that was initially generated by the divergence becomes transient, and ultimate convergence in world economic growth can be achieved.

## 8. THE CONVERGENCE HYPOTHESIS AND INITIAL CONDITIONS

The convergence hypothesis is to taken to examine whether or not the effects of initial conditions eventually disappear. Indeed, the growth literature is assigned to answer two questions concerning per capita income differences across countries or regions. First, the observed cross-country differences in per capita incomes are or not transient? Second, if the differences in per capita incomes are permanent, does that performance reflect structural heterogeneity or the role of initial conditions in determining long-run outcomes? If the differences in per capita incomes are temporary, unconditional convergence (to a common long-run level) is occurring. If the differences are permanent solely because of cross-country structural heterogeneity, conditional convergence is occurring. If initial conditions determine, in part at least, long-run outcomes, and countries with similar initial conditions exhibit similar long-run outcomes, then there is evidence of convergence clubs.

Growth literature focuses on relative rather than absolute inequality. To be exact, researchers are usually more interested in whether the ratio of income between two countries exhibits persistence than an absolute difference, particularly since sustained economic growth will imply that a constant levels difference is of asymptotically negligible size when relative income is considered. Therefore, we use $\log y_{i,t}$, the log level of per capita output in country i at time t, rather than $y_{i,t}$.

As we said above, convergence hypothesis associate the log level of per capita output in country i, $\log y_{i,t}$ with initial conditions, $r_{i,0}$. An answer to the questions of the growth literature would be to set that initial conditions do not matter in the long-run if

$$\lim_{t\to\infty} \mu\left(\log y_{i,t} \mid r_{i,0}\right) \text{ does not depend on } r_{i,0} \qquad (18)$$

where μ(•) is a probability measure. It is remarkable that many empirical studies of convergence are often focused on whether long-run per capita output depends on initial stocks of capital. This fact represents how the definition of equation (18) is connected with empirical growth studies.

A key question that is assigned to growth economists is whether certain initial conditions lead to persistent differences in per capita output between countries or regions. Thus, equation (18) is commonly used to define convergence between two economies. Let $\|\ \|$ denote a metric for computing the distance between probability measures. Then countries i and j exhibit convergence if

$$\lim_{t\to\infty} \left\| m\left(\log y_{i,t} \mid r_{i,0}\right) - m\left(\log y_{j,t} \mid r_{j,0}\right) \right\| = 0 \qquad (19)$$

However, growth economists are generally interested in average income levels. Given this fact, equation (19) implies that countries i and j exhibit convergence in average income levels in the sense that

$$\lim_{t\to\infty} E\left(\log y_{i,t} - \log y_{j,t} \mid \rho_{i,0}, \rho_{j,0}\right) = 0 \qquad (20)$$

An alternative measure of convergence has been proposed by Bernard and Durlauf (1996). Indeed, this type of convergence examines whether contemporaneous income differences are expected to diminish. In particular, Bernard and Durlauf suggest a form of partial convergence that if $\log y_{i,0} > \log y_{j,0}$, it amounts to asking whether

$$E\left(\log y_{i,t} - \log y_{j,t} \mid \rho_{i,0}, \rho_{j,0}\right) < \log y_{i,0} - \log y_{j,0} \qquad (21)$$

A number of modifications of these definitions have been proposed. Hall, Robertson, and Wickens (1997) suggest an alternative convergence definition that introduces the requirement under which the variance of output differences diminish to 0 over time, i.e.

$$\lim_{t\to\infty} E\left(\left(\log y_{i,t} - \log y_{j,t}\right)^2 \mid \rho_{i,0}, \rho_{j,0}\right) = 0 \qquad (22)$$

implying that convergence requires output for a pair of countries to behave similarly in the long-run. Nevertheless, this requirement is too strong because it does not allow us to consider the output series as stochastic in the long-run. One of the key implications of equation (22) is the absence of convergence if countries are perpetually subjected to distinct business cycle shocks. In addition, Hall, Robertson, and Wickens (1997) point out that convergence under equation (22) fails to control for long-run deviations whose current direction is not predictable. This fact is recorded as a central weakness of convergence definition under equation (20). This point is easy to understand if we suppose that $\log y_{i,t} - \log y_{j,t}$ is a random walk with current value 0. In this case, the convergence definition under the equation (20) would be fulfilled, although output deviations between countries i and j will become arbitrarily large at some future date.

Pesaran (2007) is more interested in the likelihood of large long-run output deviations and proposes an alternative convergence definition based on this idea. In this context, convergence is defined as

$$\lim_{t\to\infty} \text{Prob}\left(\left(\log y_{i,t} - \log y_{j,t}\right)^2 < C^2 \mid \rho_{i,0}, \rho_{j,0}\right) > \pi \qquad (23)$$

where C denotes a deviation magnitude and π is a tolerance probability. This convergence definition introduces an analysis under which output deviations are economically important and we can allow for some flexibility with respect to the probability with which these output deviations occur.

A central weakness of the above convergence definitions is that they do not allow for the distinction between the long-run effects of initial conditions and the long-run effects of structural heterogeneity. This is a serious limitation from the perspective of growth theory. Steady state effects of initial conditions imply the existence of convergence clubs whereas steady-state effects of structural characteristics do not. Hence, one of the most useful contributions in empirical work would be the ability to distinguish between initial conditions $r_{i,0}$ and structural characteristics $q_{i,0}$. In order to achieve such a contribution, we can modify equation (19) so that

$$\lim_{t\to\infty} \left\| m\left(\log y_{i,t} \mid r_{i,0}, q_{i,0}\right) - m\left(\log y_{j,t} \mid r_{j,0}, q_{j,0}\right) \right\| = 0 \text{ if } q_{i,0} = q_{j,0} \quad (24)$$

implying that countries i and j exhibit convergence. The notions of convergence in expected value (equation (20) may be modified in this way as well,

$$\lim_{t\to\infty} E\left(\log y_{i,t} - \log y_{j,t} \mid r_{i,0}, q_{i,0}, r_{j,0}, q_{j,0}\right) = 0 \quad (25)$$

as can partial convergence in expected value (equation (21)) and the other convergence concepts discussed above.

In empirical works, stocks of initial capital are treated as initial conditions and other variables are treated as structural heterogeneity. This is a common practice which most of empirical works deal with the distinction between initial conditions and structural heterogeneity. Given this fact, structural heterogeneity is taken to be captured both by the Solow variables X and by the control variables Z that appear in cross-country growth regression (12). This practice may be criticized if these variables are themselves endogenously determined by initial conditions.

# 9. EMPIRICAL TECHNIQUES

In this section we present the main techniques, namely β-convergence, σ-convergence and time-series approach, that have been employed to test the convergence hypothesis. We explicitly present the theory and its implications as well as the methodology and the weaknesses for each of these techniques respectively.

## 9.1 CROSS-SECTION REGRESSION: β-CONVERGENCE

Statistical analyses of convergence have largely focused on the properties of β in regressions of the form (12). β-convergence, defined as β<0 is easy to evaluate because it relies on the properties of a linear regression coefficient. It is also easy to interpret in the context of the Solow growth model, since the finding is consistent with the dynamics of the model. We quoted above that according to the neoclassical model, the actual value $y_t$ is a weighted average of initial income, $y_0$, and steady-state income, $y^*$. Given this fact, the following equation holds:

$$\log y_t = e^{-lt} \log y_0 + \left(1 - e^{-lt}\right) \log y^* \qquad (26)$$

Subtracting $\log y_0$ from both sides of (26) and adding a stochastic term ε yields:

$$\log y_t - \log y_0 = -\left(1 - e^{-lt}\right) \log y_0 + \left(1 - e^{-lt}\right) \log y^* + e_t \qquad (27)$$

Alternatively,

$$g_{i,0,t} = b \log y_0 - b \log y^* + e_t \qquad (28)$$

where $g_{i,0,t}$ is the growth rate of an economy over the period 0 to t, β is assumed to be equal to $\left(1 - e^{-lt}\right)$, λ is the speed of convergence, $y_0$ is the initial value of per capita income and $y^*$ accounts for the variables that proxy(determine) the steady-state value of per capita income.

The list of variables that proxy $y^*$ can be quite long. Sala-i-Martin (1997) finds 22 out of 59 variables to have a significant effect on economic growth. His list include: regional variables (e.g. location, distance from the equator), political variables (e.g. civil liberties, number of revolutions), religious variables (e.g. Buddhist, Catholic), market distortion, types of investment, primary sector production, openness to world markets, type of economic system and former Spanish colonies.

The economic intuition of the equation (28) is that if two countries have common steady-state determinants and are converging to a common balanced growth path, the country that begins with a relatively low level of initial income per capita has a lower capital-labor ratio and hence a higher marginal product of capital. A given rate of investment then translates into relatively fast growth for the poorer country. In other words, if $g_{i,0,t}$ is regressed only on $\log y_0$, then a negative β suggests that per capita income in the low-income economies has grown faster than in the high-income economies over the sample period. Such an outcome is called absolute β-convergence indicating the sample economies have more or less the same steady-state values.

However, a non-negative coefficient β does not necessarily invalidate the convergence implication of the neoclassical model. Rather, it would suggest that sample economies may be converging to different steady-state values. A negative β in the presence of variables that determine the steady-state value $y^*$ would signify a conditional β-convergence. Typically, the unconditional β-convergence hypothesis is supported when applied to data from relatively homogeneous groups of economic units such as the states of the US, the OECD, or the regions of Europe. In contrast there is generally no correlation between initial income and growth for data taken from more heterogeneous groups such as a broad sample of countries of the world.

There is a large body of studies of β-convergence, studies that are differentiated by country set, time period and choice of control variables. Many cross-section studies employing the β-convergence approach find estimated convergence rates of about 2% per year. This result is found in data from such diverse entities as the countries of the world (after the addition of conditioning variables), the OECD countries, the US states, the Swedish countries, the Japanese prefectures, the regions of Europe, the Canadian provinces, and the Australian states, among others. It is also found in data sets that range over time periods from the 1860's through the 1990's. In fact, there is some variation in estimated convergence rates, but the range is relatively small. Estimates generally range between 1% and 3%.

One of the most notable researches concerning the unconditional β-convergence is that of Baumol's (1986). He applied a growth-initial level regression in a sample of 16 countries of OECD over the years 1870-1979 and he found a significant negative coefficient in the variable of initial per capita income. In addition, he tried to extend this relationship in a sample of 72 countries but the results were not robust to convergence. Thus, Baumol introduced the concept of "club convergence" through the difference of these results depending on the size of the sample. However, De Long(1988) shows that if one adds to Baumol's sample six economies that were rich in 1870, the convergence will disappear. This criticism is known as the "selection bias", implying that Baumol's sample included economies that had converged ex post.

Barro and Sala-i-Martin (1992) and Sala-i-Martin (1996) assert that with the right conditioning variables, a rate of convergence of 2% per year is uniformly obtained across a broad range of samples. They draw two implications: First, in a Cobb-Douglas production function for aggregate output, physical capital's coefficient is over 0.9, appreciably larger than the 0.4 implied by factor shares in national income accounts. Second, convergence occurs: the poor do catch up with the rich.

Sala-i-Martin (1996) presents evidence of absolute β-convergence within the following economies: 48 states in the United States (1880-1990), 47 prefectures in Japan (1955-1990) and 90 regions in Europe (1950-1990). The following regions also exhibit absolute convergence: 11 regions in Germany (1950-1990), 11 regions in UK (1950-1990), 21 regions in France (1950-1990), 20 regions in Italy (1950-1990), 17 regions in Spain (1955-1987) and 10 provinces in Canada (1961-1991). Remarkably, Sala-i-Martin reports a speed of convergence of about 2% across these regions. A speed of convergence equivalent to 2% implies that an economy closes half the gap with its steady-state value in 35 years.

Mankiw, Romer, and Weil (1992) provide an essentially equivalent β-convergence analysis when they add human capital investment as an additional control. Their analysis differs from the vast majority of such studies in that their modification of the basic growth regression is justified by an explicit economic model. Namely, they estimate the exact law of motion generated by the Solow model with Cobb-Douglas technology. In particular, Mankiw, Romer, and Weil found an estimated convergence rate |λ| equal to 0.014, similar to Barro and Sala-i-Martin's 2%. However, the estimate of the coefficient for physical capital, $a_p$, is only 0.43, in line with physical capital's factor share in national income accounts.

The key contribution in Mankiw, Romer, and Weil is to alter Barro and Sala-i-Martin's first conclusion. In Mankiw, Romer and Weil a low estimated rate of convergence does not imply a large coefficient $a_p$ for physical capital. Indeed, Mankiw, Romer and Weil find convergence rates similar to Barro and Sala-i-Martin's estimates. The difference between the two papers is the structural interpretation of that 2% rate of convergence.

Absolute convergence for samples that include developed as well as developing economies is invariably rejected. Mankiw, Romer and Weil (1992) show that while absolute convergence holds for a sample of OECD economies over the years 1960-1985 (β = -0.341, t-statistic = 4.31), it gets rejected in a broader sample of 75 economies (β = -0.004, t-statistic = 0.08). For a sample of 98 economies they discover absolute divergence (β = 0.094, t-statistic = 1.90). They find, however, strong conditional convergence for all three samples.

Cheshire and Carbonaro (1995) examined GDP per capita growth rates for a set of 118 urban regions of the EU for the time period 1980-1990. These authors argued that the estimated convergence rates depend on the conditioning variables in cross section regressions. They reported mixed results depending on the specification of the models. Convergence was confirmed when the conditioning variables were those consistent with the standard neoclassical model, but their results are not robust. The introduction of other variables in cross section regressions such as proxies for scale economies in cities, congestion, and other costs in large cities and spatial proximity to other city regions led to evidence of divergence.

Yin, Zestos and Michelis (2000) examined whether EU countries have been successful in integrating their economies during the period 1960-1995. In particular, they studied whether there was a tendency for convergence of the real per capita GDP among the EU countries. Two measures of economic convergence were utilized: the cross-sectional standard deviation of the real per capita GDPs, and the measure of convergence of the real per capita GDPs based on the neoclassical growth model. The empirical results suggest evidence of ongoing convergence among the EU economies during the entire sample period with the exception of the sub-period 1980-1985.

When the 10-year sub-periods were employed, it was shown that convergence in the EU was going strong and uninterrupted. This study also examined convergence/divergence within and between EU subgroups of countries. Convergence was supported between EU subgroups of countries and within each EU subgroup but in different and explainable degrees. Comparing convergence among five continents, EU15 and APEC they found that the EU is the only group of countries that succeeded in pursuing economic integration during the last three and a half decades. The study also revealed that existing economic, socio-political and policy differences among EU members countries reduce the rate of convergence in the EU. It is difficult to pinpoint the exact reasons that contributed to convergence of the European Union. They suggested that adopted EU policies played a crucial role in integrating the EU economies. The creation of Customs Union and the formation of a Common Market along with the international trade agreements spearheaded by the the GATT led to global trade liberalization. Trade liberalization among the EU countries, structural policies aiming to integrate the economies as well as the proximity of these countries, have all contributed to economic convergence of the EU countries.

Matkowski and Prochniak (2004) have tested growth and cyclical convergence among the 8 Central Eastern Europe (CEE) accession countries and the EU. Their results indicate that there is a clear-cut convergence among the eight EU accession countries of CEE as to income levels. The GDP growth rates in the period 1993-2001 were generally negatively correlated with the initial GDP per capita level. Income differences between individual countries reveal a decreasing trend, especially during 1997-2001. As regards cyclical convergence, CEE countries should be divided into three subgroups: (a) Czech Republic and Slovak Republic (b) Hungary and Poland (c) the Baltic states. Slovenia may be included in one of the two first subgroups. The countries in each subgroup reveal a good conformity of cyclical fluctuations while the correlation with other subgroups is weak. All the considered CEE countries reveal a strong economic convergence towards the EU, both as regards income levels and business cycles. The accession countries tend to develop faster than the elder EU members. The income gap between CEE and EU is generally decreasing, although it still remains large. Most CEE countries also reveal quite a good conformity of cyclical fluctuations with the euro area. The existing trade and capital links between CEE countries and the EU are already quite strong. Therefore, we should not except a major improvement in their real economic convergence just after the accession. Moreover, the possibility of some divergence tendencies can not be excluded.

Despite the many confirmations of this result now in the literature, the claim of global conditional β-convergence remains controversial. Here we review the primary problems with the β-convergence literature.

First of all, there is much criticism concerning the robustness of β-convergence test with respect to the choice of control variables. In particular, complexities arise in terms of the specification of steady-state income as we move from unconditional to conditional β-convergence. This is attributed to the dependence of steady-state on Z. Theory is not always a good guide in the choice of elements of Z. As a result, a “growth regression industry” has been generated as researchers have added a vast variety of plausibly relevant variables to the baseline Solow specification leading to different formulations of equation (12). As a result, one can identify variants of (12) where convergence appears to occur as $\hat{\beta} < 0$ as well as variants where divergence occurs, i.e. $\hat{\beta} > 0$

Moreover, it is unclear what exercise a researcher conducts by adding a particular control variable, even when the variable is motivated by a particular economic theory. There is an immense range of extensions of the neoclassical model through factors such as inequality, political regime, or trade openness. These factors are often highly correlated with one another, and are neither mutually exclusive nor prioritized as possible explanations of growth. Hence, it is difficult to assign much import to the statistical significance of an arbitrarily chosen subset of possible controls. Therefore, claims that these regressions are able to identify economic structure, can be characterized as unpersuasive.

A second criticism that is sometimes made of the empirical convergence literature is based on the failure to account for the endogeneity of the explanatory regressors in growth regressions. Endogeneity raises the issue with respect to the relationship between β-convergence and economic convergence. Focusing on the Solow regressors, the value of β can fail to illustrate how initial conditions affect expected future income differences if the population and saving rates are themselves functions of income. Hence, β > 0 may be compatible with at least partial economic convergence, if the physical and human capital savings rates depend, for example, on the level of income. In contrast, β < 0 may be compatible with economic divergence if the physical and human capital accumulation rates for rich and poor are diverging across time.

In addition, the use of cross-section regressions to interpret causal growth relationships requires strong homogeneity assumptions. For example, it is necessary to believe that the coefficients in the regression are constant across economies. Furthermore, following an argument in Brock and Durlauf (2001), it is necessary to believe that the residuals are indistinguishable given a researcher’s prior information about the countries with which the residuals are associated. A formal way to state this is that regression errors should exhibit a certain conditional exchangeability condition. Intuitively, one needs to believe that there is no prior reason why the residuals for one subgroup of countries should have a different mean than for some other subgroup.

Furthermore, an estimation of equation (12) could result in a negative β, yet shocks to the system would prevent a convergence of per capita income. Consider a lower-income country that grows so fast that its per capita income surpasses that of a higher-income country, leaving as much dispersion at the end of the period as at the beginning, although at the other direction. In this case, equation (12) would yield a negative β despite no convergence. If convergence occurs, one would obtain a negative β, but a negative β does not necessarily imply convergence.

Bernard and Durlauf (1996) criticize the β-convergence approach on the grounds that a negative β can be estimated in equation (12) even if only some economies converge. According to them, researchers that applied β-convergence tests, applied ordinary least squares to equation (12). Hence, they ignore the presence of control variables without any loss of generality. Taking into account two time series and observing that $g_{i,T}$ = $T^{-1} \sum_{t=1}^{T} \Delta y_{i,t}$, where $\Delta y_{i,t} = y_{i,t} - y_{i,t-1}$, equation (12) (without accounting for any control variables) implies that

$$T^{-1} \sum_{t=1}^{T} \Delta y_{i,t} - T^{-1} \sum_{t=1}^{T} \Delta y_{j,t} = \beta( y_{i,0} - y_{j,0}) + e_{i,T} - e_{j,T} \quad (29)$$

If $y_{i,0} - y_{j,0}$ is positive, then the requirement that β is negative implies that the expected value of $T^{-1} \sum_{t=1}^{T} \Delta y_{i,t} - T^{-1} \sum_{t=1}^{T} \Delta y_{j,t}$ is negative. From the perspective of bivariate comparisons, the cross-section β tests consequently examine whether the average change in the per capita output of an initially poorer country exceeds that of an initially richer country.

Equivalently, letting $\overline{y_{i,0}} = I^{-1} \sum_{i=1}^{I} y_{i,0}$ and $\overline{g_{i,T}} = I^{-1} \sum_{i=1}^{I} g_{i,T}$, the ordinary least squares estimator $\hat{b}$ can be written as

$$\hat{b} = \sum_{i=1}^{I} f_i y_i \quad (30)$$

where

$$f_i = \frac{\left(y_{i,0} - \bar{y}_{i,0}\right)^2}{\sum_{i=1}^{I}\left(y_{i,0} - \bar{y}_{i,0}\right)^2} \quad (31)$$

and

$$\gamma_i = \frac{g_{i,T} - \bar{g}_{i,T}}{y_{i,0} - \bar{y}_{i,0}} \qquad (32)$$

In other words, $\hat{b}$ equals a weighted average of the ratio of differences of growth rates from the sample means to differences of initial incomes from the sample mean. Cross-section tests therefore require that a weighted average of countries with above average initial incomes grow at a slower rate than the mean growth for the cross-section. Ultimately, in a context, in which we associate the convergence hypothesis with the neoclassical model, the testable restriction in cross-section tests requires that the first moments of the stochastic processes governing growth rates differ for initially rich and poor economies.

This derivation shows how the cross-section tests may be interpreted with respect to equation (21). Since $\hat{b}$ is a weighted average of $\gamma_i$'s, a negative $\hat{b}$ means that the output differences between some pairs of countries have declined over the sample. Hence, for the information set consisting exclusively of a constant, some pairs of countries are converging in the sense of equation (21). However, a crucial weakness of the cross-section tests is that they can not identify groupings of countries which are converging. Ultimately, cross-section tests are ill-designed to analyze data where some countries are converging while others are not. In addition to this, Bernard and Durlauf (1995) point out that in the β-convergence approach, the null hypothesis is that no economies are converging versus the alternative that all economies are. This approach, as a result, is not suited for cases in which only some economies converge.

Evans and Karras (1996a) argue that the β-convergence approach would produce valid inferences under only "incredible assumptions". To understand the essence of their argument, Evans and Karras describe convergence as follows:

$$\lim_{k\to\infty} E_t\left(\log y_{i,t+k} - \log \bar{y}_{t+k}\right) = a_i \qquad (33)$$

where $y_{i,t+k}$ is the per capita income of economy i at time t+k, $\bar{y}_{t+k}$ is the mean of $y_{t+k}$ across economies and $a_i$ is a constant value. In this formulation convergence requires that $\log y_{i,t}$ be nonstationary and $\left(\log y_{i,t} - \log \bar{y}_t\right)$ be stationary for every economy.

In order to produce equation (12) valid inferences, $e_i$ and $\log y_{i,0}$ need to be uncorrelated. But this condition would hold if and only if $\left(\log y_{i,t} - \log \bar{y}_t\right)$ is generated by the process

$$\left(\log y_{i,t} - \log \bar{y}_t\right) = a + b\left(\log y_{i,t-1} - \log \bar{y}_{t-1}\right) + u_{i,t} \qquad (34)$$

where $u_{i,t}$ is a serially uncorrelated stochastic term. It is the necessary and sufficient conditions underlying the data generating process (34) that render β-convergence virtually useless. These conditions require that "the dynamical structures of the economies have identical first-order autoregressive representation. Every economy affects every other economy completely symmetrically. And the vector of variables control for all permanent cross-economy differences" (Evans and Karras, 1996b). They call these conditions "incredible" and state that, in the absence of good luck and happenstance, equation (12) will produce invalid inferences.

## 9.2 CROSS-SECTION DISTRIBUTION: σ-CONVERGENCE

A second approach to convergence focuses on the behavior of the cross-section distribution of income in levels. Unlike the β-convergence approach, the focus of this literature has been less on the question of relative locations within the income distribution, i.e. whether one can expect currently poor countries to either equal or exceed currently affluent countries, but rather on the shape of the distribution as a whole. Questions of this type naturally arise in microeconomic analyses of income inequality, in which one may be concerned with whether the gap between rich and poor is diminishing, regardless of whether the relative positions of individuals are fixed over time.

Hence, an alternative test of the convergence hypothesis has been proposed in the literature, known as σ-convergence. In this approach, the investigator calculates the standard deviation (σ) of the logarithm of real per capita income across sample economies for each year of the sample period. If $y_{i,t} = \ln\left(Y_{i,t}\right)$, where $Y_{i,t}$ is the real per capita income in country i at time t, and $\sigma^2 = \sum_i \left(y_{it} - \bar{y}_t\right)^2 / N$ is the variance of $y_{i,t}$ across countries, then σ-convergence occurs when the cross-section standard deviations of per capita incomes diminish over time.

To be more exact, the concept of σ-convergence is related to the income distribution of a set of economies. In fact, the existence of σ-convergence implies that the world income distribution shrinks over time. Thus, for example, if we consider the variance (or standard deviation) of the log of GDP at a certain time t and at time t+k (k>0), we say that there is σ-convergence for a given set of economies and for a given period of time (k), if:

$$\sigma_t^2 \succ \sigma_{t+k}^2 \quad (35)$$

This definition is designed, like β-convergence, to formalize the idea that contemporary income differences are transitory, but does so by asking whether the dispersion of these differences will decline across time.

We assume that the real per capita incomes are determined by the following autoregressive process:

$$y_{i,t} = \rho\, y_{i,t-1} + u_{i,t} \qquad t = 2,\ldots,T \quad i = 1,\ldots,N \quad (36)$$

where the intercept is suppressed. The $y_{i,1}$ are supposed to be identically and independently distributed (i.i.d.) **N**($\mu_1$, $\sigma_1^2$) and to be independent of the $u_{i,t}$ , which are i.i.d. **N**(**0**,$\sigma_u^2$). Further, we find from equation (36) that the variance $\sigma_t^2$ of $y_{i,t}$ is determined as follows:

$$\sigma_t^2 = \rho^2 \sigma_{t-1}^2 + \sigma_u^2 \qquad t = 2,\ldots,T \quad (37)$$

The null hypothesis of no convergence is equivalent to the parameter restriction $\rho^2 = 1 - (\sigma_u^2/\sigma_1^2)$. Real per capita incomes converge over time in case $\rho^2 < 1 - (\sigma_u^2/\sigma_1^2)$. In this case, the variance decreases over time, but the decrease becomes less severe over time and the variance converges to $\sigma_u^2/\left(1-\rho^2\right)$.

Economists have acknowledged that β-convergence is not a sufficient condition for σ-convergence. In this section, we demonstrate that β-convergence is a necessary but not sufficient condition for σ-convergence.

In particular, following Sala-i-Martin's (1996) exposition, assume that β-convergence holds for economies i = 1,…,N. Natural log-income of the i-th economy can be approximated by

$$\ln y_{i,t} = \alpha + (1-\beta)\ln y_{i,t-1} + u_{i,t} \quad (38)$$

Where 0 < β < 1 and $u_{i,t}$ has mean zero, finite variance, $\sigma_u^2$, and is independent over t and i. Because α is assumed constant across economies, balanced growth paths are identical, implying the case of absolute β-convergence. If we manipulate equation (38), it yields

$$\ln\left(\frac{y_{i,t}}{y_{i,t-1}}\right) = \alpha - \beta \ln y_{i,t-1} + u_{i,t} \quad (38')$$

Thus, β > 0 implies a negative correlation between growth and initial log income.

The sample variance of log income in t is given by

$$\sigma_t^2 = \left(\frac{1}{N}\right)\sum_{i=1}^{N}\left[\ln y_{i,t} - \mu_t\right]^2 \quad (39)$$

where $m_t$ is the sample mean of (log) income. The sample variance is close to the population variance when N is large, and (38) can be used to derive the evolution of $s_t^2$:

$$s_t^2 \cong (1-b)^2 s_{t-1}^2 + s_u^2 \qquad (40)$$

Only if 0 < β < 1 is the difference equation stable, so β-convergence is necessary for σ-convergence. If β≤ 0 the variance increases over time. If β=1 the variance is constant and if β > 1 the partial correlation between (log) income and its previous-period value would be negative and the series would oscillate, potentially from positive to negative values and back, making little economic sense.

Given 0 < β < 1, the steady-state variance is,

$$\left(s^2\right)^* = \frac{s_u^2}{\left[1-(1-b)^2\right]} \qquad (41)$$

Thus, the cross-sectional dispersion falls with β but rises with $s_u^2$. Combining (40) and (41) yields,

$$s_t^2 = (1-b)^2 s_{t-1}^2 + \left[1-(1-b)^2\right]\left(s^2\right)^* \qquad (42)$$

which is a first-order linear difference equation with constant coefficients. Its solution is given by,

$$s_t^2 = \left(s^2\right)^* + (1-b)^{2t}\left[s_0^2 - \left(s^2\right)^*\right] + c(1-b)^{2t} \qquad (43)$$

where c is an arbitrary constant. Thus, as long as 0 < β < 1, we have |1-β| < 1, which implies that

$$\lim_{t\to\infty}(1-b)^{2t} = 0 \qquad (44)$$

This ensures the stability of $s_t^2$ because it implies that,

$$\lim_{t\to\infty} s_t^2 = \left(s^2\right)^* \qquad (45)$$

Moreover, since $(1-b) \mathbf{f}\ 0$, the approach to $\left(s^2\right)^*$ is monotonic.

It follows, therefore, that the variance will increase or decrease towards its steady-state value depending on the initial $s_0^2$. Therefore, $s_t^2$ can be rising even if β-convergence is the rule. Intuitively, economies can be β-converging towards one another while, at the same time, random shocks are pushing them apart. Despite β-convergence, if the initial dispersion of income levels is, by chance, small relative to the variance of random shocks then the dispersion of incomes will converge towards its steady-state value from below. It is noteworthy that in equation (43) the parameter β governs the speed at which the variance approaches its steady-state value because, according to equation (38), it governs how long the effects of shocks persist.

Other scenarios where β-convergence does not imply σ-convergence arise when the parameter α varies across economies, implying the case of conditional β-convergence. Intuitively, consider two economies, A and B, where both economies begin at the same level of income. However, assume that B begins on its balanced growth path while A begins far below its balanced growth path, and assume that β-convergence holds. The initial variance, $S_0^2$, will be zero, but $S_t^2$ will grow over time as A grows faster than B and approaches a higher balanced growth path. Indeed, β-convergence is the reason for the increasing variance. Ultimately, in real economies, σ-convergence would also depend on whether or not disturbances are correlated, and have constant variances across time and economies.

Many studies have focused on changes in the dispersion of income differences across time. The key finding, however, is that there is no evidence of σ-convergence when one examines a full cross-section sample of countries. In contrast, when one restricts the analysis to developed economies, σ-convergence appears to be present.

Sala-i-Martin (1996) examined the behaviour of the dispersion of GDP per capita for a data set of 110 countries between 1960 and 1990. His results pinpoint that the dispersion, σ, increases steadily from σ = 0.89 in 1960 to σ = 1.12 in 1980. Therefore, he concludes that the cross-country distribution of world income has become increasingly unequal. Indeed, Sala-i-Martin asserts that we live in a world where economies have diverged in the sense of σ over the last 30 years.

However, Sala-i-Martin's results are different when the analysis is restricted to developed economies. To be exact, Sala-i-Martin examined the cross-sectional standard deviation for the log of per capita personal income net of transfers for 48 U.S. states from 1880 to 1992. His results presents that the dispersion declined from 0.54 in 1880 to 0.33 in 1920, but then rose to 0.40 in 1930. This rise reflects the adverse shock to agriculture during the 1920s. After the 1920s shock, dispersion fell to 0.35 in 1940, 0.24 in 1950, 0.21 in 1960, 0.17 in 1970, and a low point of 0.14 in 1976. The long-run decline stopped in the mid-1970s, after the oil shock, and $S_t$ rose to 0.15 in 1980 and 0.19 in 1988. The rise in income dispersion was reversed in the last two years of the 1980s and it kept falling through 1992.

Moreover, Sala-i-Martin calculated the cross-sectional standard deviation for the log of per capita income, $S_t$, for the 47 Japanese prefectures from 1930 to 1990. The results exhibit that the dispersion of personal income increased from 0.47 in 1930 to 0.63 in 1940. One explanation of this phenomenon is the explosion of military spending during the period. The cross prefectural dispersion has decreased dramatically since 1940: it fell to 0.29 by 1950, to 0.25 in 1960, to 0.23 in 1970 and hit a minimum of 0.125 in 1978. It has increased slightly since then: $S_t$ rose to 0.13 in 1980, 0.14 in 1985 and 0.15 in 1987. Income dispersion has been relatively constant since then. One popular explanation of the increase in dispersion for the 1980s is the take-off of the Tokyo region from the rest of Japan.

Sala-i-Martin examined the behaviour of $s_t$ for the regions within the largest five countries in the E.U.: Germany, the United Kingdom, Italy, France, and Spain. The overall pattern shows declines in $s_t$ over time for each country, although little net change has occurred since 1970 for Germany and the United Kingdom. In particular, the rise in $s_t$ from 1974 to 1980 for the United Kingdom - the only oil producer in the European sample - likely reflects the effects of oil shocks.

Carree and Klomp (1997) investigated σ-convergence by computing the statistic for a data set of per capita gross domestic product for 22 OECD countries for the 1950-1994 period. They did the same for the period 1960-1985. For the period 1950-1994 the results indicates that the cross-section variance of per capita incomes has decreased. In 1950 it was 0,3160, while it was only 0,1215 in 1994. Carree and Klomp conclude that there has also been convergence for the period 1960-1985, in which the variance decreased from 0,2320 to 0,1424. They also examined some shorter time periods, namely, the time period 1950-1994 divided into four subperiods of 12 years each and their results also support σ-convergence. The value of variance of per capita income lie between 0.019 (period 1960-1985) and 0.036 (period 1972-1983). A similar pattern is found by Den Haan (1995) for 49 states from 1940 to 1990. The dispersion of per capita income in his sample has become much smaller over this time period, but seems to have settled down in the 1970s and 1980s.

Young, Higgins and Levy (2007) use USA county-level data containing over 3.000 cross-sectional observations between 1970 and 1998 and demonstrate that σ-convergence does not hold across the U.S., or within the vast majority of the individual U.S. states. In particular, the 1998 standard deviation of log income for the full U.S. sample (0.2887) is about 5.8 percent greater than that of 1970 (0.2728), a difference that is significant at the 1 percent level. In only 2 out of 50 states (Kansas and Oklahoma) is the 1998 standard deviation of log income less than that of 1970 (at the 10 percent level or better). On the other hand, for 24 states the 1998 standard deviation of log income is significantly larger (at the 10 percent level or better). Thus, for the vast majority of the individual US states, as well as for the full U.S., σ-divergence occurred from 1970 to 1998. This findings are ultimately consistent with that of Tsionas' (2000), despite the fact that Tsionas' data set is nearly a decade shorter. Indeed, Tsionas finds that the cross sectional variance has fluctuated very little in the 20-year period from 1977 to 1996.

However, σ-convergence approach has some difficulties, too. While a diminution in σ is evidence of convergence, it does not necessarily support the convergence hypothesis. The reason is that the faster growth of the lower-income economies in the sample may be due to larger investment or some growth-inducing policies rather than the convergence forces. The σ convergence approach is not connected with why σ is declining – a point which is central in testing the convergence hypothesis.

One limitation to this approach is that it is not clear how one can formulate a sensible notion of conditional σ-convergence. A particular problem in this regard is that one would not want to control for initial income in forming residuals, which would render the concept uninteresting as it could be generated by nothing more than time-dependent heteroskedasticity in the residuals. On the other hand, omitting income would render the interpretation of the projection residuals problematic since initial income is almost certain to be correlated with the variables that have been included when the residuals are formed.

It is relatively difficult to interpret properties of the cross-country income distribution in the context of economic convergence in the sense of equation (20). To see why this is so, it is useful to focus on the absence of a clear relationship between β-convergence, which measures the relative growth of rich versus poor countries and σ-convergence, which focuses explicitly on the distribution of countries. These two convergence notions do not have any necessary implications for one another, i.e. one may hold when the other does not. What is important is that σ-convergence is not an implication of β-convergence and does not speak directly to the question of the transience of contemporary income differences. The erroneous assertion that β-convergence implies σ-convergence is known as Galton's fallacy and was introduced into the modern economic growth context by Friedman (1992) and Quah (1993a).

In particular, Francis Galton noticed that the sons of tall fathers are shorter than their fathers, while the sons of short fathers are taller than their fathers. This observation, he concluded, suggests a regression towards the mean. The conclusion, however, conflicts with the fact that the deviation from the mean height does not diminish over time. (Galton was unable to resolve this dilemma). Similarly, low-income economies may grow faster than the high-income economies, producing a negative β in equation (12), but the dispersion in income data may not diminish over time due to shocks to the economies. Indeed, Quah shows that a negative coefficient on initial income is consistent with non-decreasing income dispersion. Quah (1996a) points out that, due to shocks to economies, σ, at best, approach a constant, not zero. As a result, this approach represents only average behaviour, revealing nothing about the entire distribution.

To understand the fallacy, suppose that log per capita output in each of N countries obeys the AR(1) process

$$\log y_{i,t} = a + f \log y_{i,t-1} + e_{i,t} \qquad (46)$$

where 0 < φ < 1 and the random variables $e_{i,t}$ are i.i.d. across countries and time. For this model, each country will, by definition (20), exhibit convergence as any contemporaneous difference in output between two countries will disappear over time. Further, it is easy to see, using $g_i = T^{-1}\left(\log y_{i,t+T} - \log y_{i,t}\right)$, that the regression of growth on a constant and initial income will exhibit β-convergence. This is immediate when one considers growth between t and t+1 which means that growth obeys

$$g_{i,t} = a + (j - 1)\log y_{i,t-1} + e_{i,t} \qquad (47)$$

where φ-1<0 by assumption. In this model, by construction, the unconditional population variance of log output is constant because the reduction in cross-section variance associated with the tendency of high income countries to grow more slowly than low-income countries is offset by the presence of the random shocks $e_{i,t}$. This indicates why σ-convergence is not a natural implication of long run independence from initial conditions. Rather σ-convergence captures the evolution of the cross-section income distribution towards an invariant measure.

In addition to this, Bliss (1999, 2000) points out that it is difficult to interpret tests of σ-convergence since these tests presume that the data generating process is not invariant. An evolving distribution for the data makes it difficult to think about test distributions under a null. Additional issues arise when unit roots are present.

## 9.3 TIME SERIES APPROACHES TO CONVERGENCE

Bernard and Durlauf (1995, 1996), Quah (1992), Evans (1998) and Hobijn and Franses (2000) provide a systematic framework for time series convergence tests. In particular, they developed an alternative approach with respect to long-run output dynamics and convergence based on time-series ideas. In this context, convergence is identified not as a property of the relation between initial income and growth over a fixed sample period, but instead of the relationship between long-run forecasts of per capita output, taking as given initial conditions.

Convergence, supported by time-series tests, suggests that the differences in per capita output across countries are always transitory in the sense that long run forecasts of the difference between any pair of countries converges to zero as the forecast horizon grows. Under the most prevailing definition given by Bernard and Durlauf, time-series convergence is defined as the equality of long-term forecasts of per capita outputs, taken at a given fixed date. Specifically, according to Bernard and Durlauf, a set of countries I is said to exhibit convergence if

$$\lim_{T\to\infty} E_t\left(\log y_{i,t+T} - \log y_{j,t+T} \middle| F_t\right) = 0 \quad \forall i, j \in I \quad (48)$$

where $F_t$ denotes some information set. This information set will typically contain various functions of time and current and lagged values of $\log y_{i,t}$ and $\log y_{j,t}$. Equation (48) implies that the long-term forecasts of per capita output are equal given the information available at t. Time series convergence implies β – convergence when growth rates are measured between t and t+T for some fixed finite horizon T. Convergence definition given by the equation (48) represents a form of unconditional convergence that is closely related to equation (20). Nevertheless, the critical distinction between time-series forecast convergence and β-convergence is that an expected reduction in contemporary differences (β – convergence) is not the same as the expectation of their eventual disappearance.

In addition, this dynamic definition has the added feature that it distinguishes between convergence between pairs of economies and convergence for all economies simultaneously. Of course, if convergence holds between all pairs then convergence holds for all. Convergence need not be an all or nothing proposition. Subgroups of economies might converge, even when not all economies do.

To operationalize time series convergence notion, a researcher examines whether the difference between per capita incomes in selected pairs of economies can be characterized as a zero-mean stationary stochastic process. Therefore, researchers have generally focused on whether deterministic or stochastic trends are present in $\log y_{i,t} - \log y_{j,t}$. The presence of deterministic or stochastic trends immediately implies a violation of equation (48). Hence, time series convergence can typically be tested using standard unit root and cointegration procedures. Under the definition of time series convergence, deterministic (nonzero) time trends in the cross-pair differences is as much a rejection of convergence as is the presence of a unit root. In particular, the presence of either a deterministic or unit root component in $\log y_{i,t} - \log y_{j,t}$ is a violation of equation (48), as either component implies that the output differences $\log y_{i,t} - \log y_{j,t}$ do not converge to zero in expected value but rather will, with probability 1, become arbitrarily large, as the forecast horizon becomes arbitrarily long.

The use of unit root is common in time series tests and it has important implications for the sorts of countries that may be tested. A central assumption, that time series tests make, is that $y_{i,t}$ can be thought of as generated by an invariant process in either levels or first differences. This assumption has significant economic implications. Specifically, Bernard and Durlauf (1996) assert that countries that start far from their invariant distributions and are converging towards them, as occurs for countries that are in transition to the steady-state in the Solow model, will be associated with $\log y_{i,t} - \log y_{j,t}$ series that do not fulfill this requirement. Therefore, time series tests based on equation (48) that are applied to such economies can produce misleading results. Intuitively, this fact is easy to understand if we assume that for country i, $\log y_{i,t} = \log y_{i,t+1}$ for all t, so that country has converged to a constant steady-state. Further, we suppose that country j has the same steady-state as country i and is monotonically converging to this state so that $\log y_{i,t} > \log y_{j,t}$ for all observations. As a result, $\log y_{i,t} - \log y_{j,t} > 0$ for all t in the sample implies that the series has a nonzero mean. Ultimately, tests that fail to account for the fact that the density of $\log y_{i,t} - \log y_{j,t}$ is changing across time can easily give misleading inferences. For example one may use a test and conclude $\log y_{i,t} - \log y_{j,t}$ possesses a nonzero mean and erroneously interpret this as evidence against convergence, when the fact that the process does not have a time-invariant mean is ignored. This argument suggests that time series convergence tests are really only appropriate for advanced economies that may plausibly be thought of as characterized by invariant distributions.

Moreover, researchers use cointegration analysis to investigate the convergence of the nonstationary real data of the sample countries. The statistical notion of cointegration is well suited to study the co-movements of a set of variables in the long run. The time series of several variables, i.e. real per capita income $Y_t$ , are cointegrated if these variables are individually nonstationary but there exists at least one linear combination of them that is stationary. The cointegrating relations have the appealing economic interpretation of long run equilibrium relationships among the variables under study. In general, if there exist r cointegrating relations in a set of p variables, there must also exist p-r common stochastic trends that move these variables around their equilibrium paths, and thus “drive” the cointegrating relations. Such cointegrated variables can not drift apart, and thus they have achieved a measure of convergence. In the bivariate case, tests for time series notion of convergence require that the outputs be cointegrated with cointegrating vector [1,-1]. If they are cointegrated with cointegrating vector [1,-λ], there are common trends in output. Thus, cointegration between economies is a necessary, but not a sufficient condition for convergence. Moreover, the condition of having achieved convergence is quite different from that of achieving convergence. If a system of variables is achieving convergence, that is, moving from an un-cointegrated state to one that is characterized by the existence of cointegration, then the underlying probability law is in flux because either its parameters or stochastic properties are changing. Traditional tests for the presence of cointegration over the entire sample period would thus tend to reject the hypothesis that the series are cointegrated if the extent of cointegration changes over time.

However, the empirical results in the time series context, applying unit root and cointegration tests, are not very favourable to convergence. Overall, the results in the time series context using unit root and cointegration tests do not constitute a strong support of convergence. In most cases, some type of structural change in the deterministic component of the series has to be introduced in the testing procedure in order to obtain better, although not overwhelming findings of convergence. However, little evidence of convergence, obtained by time-series tests, is puzzling because a simple graphical observation of long term or even medium term per capita output statistics seem to indicate that most countries (at least developed ones) have converged over time (for an illustration see Figure 3).

Evans and Karras (1996a) devise a convergence test to avoid the problems that are associated with β-convergence. In particular, they set a certain data generating process, by postulating the following equation for economy n at time t:

$$\Delta\left(\log y_{n,t} - \log \bar{y}_t\right) = a_n + b_n\left(\log y_{n,t-1} - \log \bar{y}_{t-1}\right) + \sum_{i=1}^{p} c_{n,i}\Delta\left(\log y_{n,t-1} - \log \bar{y}_{t-1}\right) + u_{n,t} \quad (49)$$

where a, b, and c are parameters, u denotes an error term, p represents the number of lags, $\log y_n$ is the logarithm of per capita output for economy n and $\log \bar{y}$ is the mean of $\log y_n$ across the sample economies.

Further, Ordinary Least Square is applied to equation (49) to obtain the standard error of estimate (σ), which in turn is used to calculate the normalized values $Z_{n,t} \equiv \left(\log y_{n,t} - \log \bar{y}_t\right)/s$ for each economy. All the variables and parameters (and the error term) are transformed accordingly. The normalized version of equation (49) is estimated to test for convergence

$$\Delta Z_{n,t} = \hat{a}_n + \hat{b}_n Z_{n,t-1} + \sum_{i=1}^{p} \hat{c}_{n,i}\Delta Z_{n,t-1} + \hat{u}_{n,t} \quad (50)$$

where "ˆ" denotes the transformed parameters and error term. If $\hat{b} < 0$, then there is evidence that the economies converge. If $\hat{b} = 0$, then there is evidence that the economies diverge. Evans and Karras applied equation (50), using annual data for 48 contiguous U.S. states over the period 1929-1991 and for 54 countries over the period 1950-1990. Using their alternative approach, they find emphatic evidence that the 48 U.S. states and the 54 countries do in fact converge. They also find strong evidence that convergence is conditional rather than absolute for both samples. Their rejection of absolute convergence for U.S. states contradicts the finding of Sala-i-Martin (1996), reviewed earlier. Overall, their evidence supports one of the basic implications of neoclassical growth models, but also indicates that a common assumption in these models, that economies are identical except for initial conditions and stochastic disturbances, is seriously deficient. By coincidence, their findings are similar to those of cross-sectional β-regressions, but this fact in no way implies that this approach is valid. Their alternative approach should be preferred because in other samples the cross-sectional β-regression can easily produce misleading conclusions.

Beyaert (2003) uses a bootstrapped method proposed by Evans and Karras (1996a). His results indicate that the richer countries of the European Union have been in absolute convergence since 1970. The poorer countries which entered the Union in the 1980's – Greece, Portugal and Spain – were only conditionally converging to their European partners at the time of their entrance. That is, their steady-state path was parallel but not as high as those of the richer members. Since 1987, the situation has evolved so that the convergence tests applied on the data between 1987 and 2000 reveal signs of absolute convergence. This evolution points out that the Structural Funds that these countries have mostly received since 1987 may have been helpful. The case of Ireland is different, because this country experienced a very intensive growth process which may have resulted not only from an efficient use of structural funds but also from the Foreign Direct Investment policy of the United States which have been using this country as an export base for their products towards the European countries. Ireland constitutes a case of such a fast catching-up process that it seems to have even "overshot" its goal of convergence, since it stands nowadays above the per capita output of any other E.U. member. As far as the Eastern European countries are concerned, his analysis focused on the case of Poland, Hungary and the Check Republic, for which the available series of per capita output cover a longer period than any other forthcoming member. The tests indicate that these countries were diverging until 1990. However, since then, they have moved to a more liberal economic system, which has been accompanied by a different evolution of their per capita output. The statistical tests indicate that they are now in a situation of conditional convergence with respect to each other, as well as with respect to the E.U. members. This is similar to the situation of Greece, Portugal and Spain at the moment they joined the E.U. So it is to hoped that these future members will be able to take full profit of their belonging to the E.U.

Carlino and Mills (1993) employ time series techniques to examine whether the pattern of relative regional per capita incomes in the U.S. during the period 1929-1990 is consistent with the convergence hypothesis. In order to do this, they apply Dickey-Fuller test to investigate the presence of unit root. The following equation yields the applied Dickey-Fuller test

$$\Delta RI_t = a + bt + g\, RI_{t-1} + \sum_{j=1}^{k} c_j \Delta RI_{t-j} \quad (51)$$

where $RI_t$ stands for the logarithm of per capita income of region i at time t relative to the aggregate per capita income of the United States. If |γ| < 0, it implies that shocks to relative regional incomes will be temporary. If |γ| = 0, it is evidence of presence of unit root, implying that shocks to relative regional incomes are permanent. The results of the ADF test indicate that the null hypothesis of a unit root can not be rejected for any of the eight U.S. regions. The finding that γ is not significantly different from zero implies that shocks to relative regional incomes are permanent. That is, once shocked, relative regional per capita incomes do not return to a deterministic trend. Moreover, they find that a number of alternative persistence measures indicate that region-specific shocks have highly persistent effects. The aforementioned findings are inconsistent with the stochastic notion of regional convergence toward some constant equilibrium.

Nevertheless, by constraining the model to follow a single trend throughout the entire sample, a one-time change in the deterministic path could erroneously be interpreted as a persistent stochastic shock. Therefore, in this context of regional convergence, it is important to consider two types of shifts in the deterministic trend: i) the compensating differentials equilibrium may have changed, and/or ii) the rate at which the various regions are converging may have changed. Accordingly, the time series model can be modified to allow for a break at time $t^*$. Ultimately, Carlino and Mills, incorporate an exogenously imposed trend break into the tests that involve estimating the following regression

$$\Delta RI_t = a_1 D_1 + a_2 D_2 + b_1 DT_1 + b_2 DT_2 + g\, RI_{t-1} + \sum_{j=1}^{k} c_j \Delta RI_{t-j} + e_t \quad (52)$$

where $D_1$ = 1 if t < $t^*$, 0 otherwise, $D_2$ = 1 if t ≥ $t^*$, 0 otherwise, $DT_1$ = t if t < $t^*$, 0 otherwise, $DT_2$ = t + $t^*$ if t ≥ $t^*$, 0 otherwise. Allowing for a break in the convergence rate in 1946, Carlino and Mills are able to reject the unit root null for three out of eight regions. This result implies that shocks to U.S. relative regional per capita income can be characterized as temporary, a finding consistent with stochastic convergence.

Li and Papell (1999) examine the unit root hypothesis in relative per capita income for 16 OECD countries from 1900 to 1989. They utilize both conventional ADF-tests and sequential tests for unit roots with endogenously determined trend breaks, they investigate unit root notion of stochastic convergence (log of relative output is trend stationary) as well as deterministic convergence (log of relative output is level stationary). Rejection of the null hypothesis of a unit root, whether or not a break is included, provides evidence of convergence.

Although the ADF is the standard methodology for testing the unit root hypothesis there is much evidence that it has serious power problems. In particular, misspecification of the deterministic trend can bias test results towards the nonrejection of the unit root hypothesis. This is especially important in the case of long time spans of data which are likely to be affected by major structural shifts. On the other hand, in the absence of a trend break allowing for structural change, as in the case of sequential Dickey-Fuller tests, will decrease the power of the tests.

Li and Papell apply conventional ADF tests to investigate unit roots in relative per capita output. They run a regression on the first difference of the logarithm of relative per capita output (to that of the group) on a constant, a trend, the lagged level of the dependent variable and k lagged first differences.

$$\Delta RI_t = m + bt + a\, RI_{t-1} + \sum_{j=1}^{k} c_j \Delta RI_{t-j} + e_t \quad (53)$$

where $RI_t$ stands for the logarithm of relative per capita output of individual country at time t, which is measured by individual country's per capita output as a percentage of the aggregate per capita output of the group.

With a time trend, the unit root hypothesis can be rejected at the 5% level for nine of the 16 countries: Australia, Canada, Denmark, Finland, France, the Netherlands, Norway, Switzerland and United Kingdom. Without a time trend, the null is rejected for five countries: Canada, Denmark, France, the Netherlands and Switzerland. Even without a break, we are able to find considerable evidence for stochastic convergence, and some evidence for deterministic convergence. Nevertheless, it is worthy of note that stochastic convergence is open to criticism because the presence of a time trend allows for permanent per capita output differences.

Moreover, Li and Papell apply sequential Dickey-Fuller tests that allow for a one-time change in both the intercept and the slope of the deterministic trend, with the time of break determined endogenously. The sequential ADF test involves estimating the following regressions

$$\Delta RI_t = m + bt + dD(T_B)_t + q\, DU_t + g\, DT_t + a\, RI_{t-1} + \sum_{j=1}^{k} c_j \Delta RI_{t-j} + e_t \quad (54)$$

where $T_B$ is the break date. The "one-time" dummy $D(T_B)_t$ = 1 if $t = T_B + 1$, 0 otherwise, the "intercept" dummy $DU_t$ = 1 if $t \mathbf{f} T_B$, 0 otherwise, and the "slope" dummy $DT_t = t - T_B$ if $t \mathbf{f} T_B$, 0 otherwise. In order to endogenise the break date selection, Li and Papell run different regressions for $T_B$ = 2,3,…,T-1. The break date is chosen to minimize the t-statistic on α. The unit root null is rejected in favour of trend stationarity, and hence evidence is provided for stochastic convergence, if α is significantly different from zero.

Incorporating trend breaks in the unit root tests significantly strengthens the findings of stochastic convergence. The unit root null can be rejected in favor of the trend stationary alternative at the 5% level for seven out of 16 countries: Belgium, Denmark, France, Germany, Japan, Switzerland, and the United States. At the 10% level, unit root can be rejected for one additional country, Austria. Some of the nonrejections appear to be caused by the decreased power of the sequential Dickey-Fuller test in the absence of a trend break. Of the remaining eight countries, the unit root can be rejected at the 5% level by the ADF test in six cases.

Overall, the ADF and sequential Dickey Fuller tests together provide strong evidence in support of stochastic convergence for 16 OECD countries. The only two countries for which they are unable to reject the unit root null at the 5% level in either test are Italy and Sweden. Therefore, for 14 out of 16 OECD countries, they are able to reject the unit root hypothesis, a result that provides evidence of stochastic convergence.

In order to investigate deterministic convergence, Li and Papell apply sequential Dickey-Fuller test to examine the unit root hypothesis in relative per capita income allowing a structural change in the mean. Specifically, they estimate the following equation:

$$\Delta RI_t = m + dD(T_B)_t + q\, DU_t + a\, RI_{t-1} + \sum_{j=1}^{k} c_j \Delta RI_{t-j} + e_t \quad (55)$$

Equation (55) differs from equation (54) by excluding the time trend and the trend dummy variable. The unit root null can be rejected in favor of the level stationary alternative at the 5% level for six out of 16 countries: Austria, Belgium, Denmark, France, Germany and the Netherlands. At the 10% level, the unit root can be rejected for two additional countries: Sweden and Switzerland. In the absence of a break, the unit root null can also be rejected at the 5% level by the ADF test for Canada. With the unit root null being rejected for over half of the countries, this result provides considerable, but by no means universal, evidence of deterministic convergence.

At this point, it is notable to quote the economic implications of the trend breaks and dummy variables. By examining the coefficients of the dummies, most of the 16 countries can be put into two categories: those which are characterized by an initial fall in output (indicated by a negative sum of the one-time and intercept dummies), and a faster growth rate afterwards (indicated by a positive slope dummy), and those which are characterized by an initial rise in output (a positive sum of the one-time and intercept dummies), followed by a slower growth (a negative slope dummy).

The trend breaks for per capita relative output mostly take place around World War II. Austria, Germany, Japan and Switzerland experience breaks around the end of the war, while Belgium, Canada, Denmark, France, Italy, the Netherlands, Norway and the United States have breaks at the beginning of the war. Ben-David and Papell(1995) find that the Great Depression instead of World War II is the cause of the breaks for the United States and Canada. The different impact of the two events on these countries may explain the discrepancy. Unlike, World War II, the Great Depression affected almost every industrialized country, it therefore fails to induce breaks in relative per capita output.

Twelve of the 16 countries experience breaks around World War II. Most display an initial fall in output, followed by a higher growth rate. The United States, which was relatively unaffected by the war, is an exception. Per capita output for the United States (relative to the group) initially rises with the onset of the war, followed by slower (relative) growth. Breaks occur in the 1920s for Australia, Finland, Sweden, and the United Kingdom. In Australia, World War I brought shortages of goods which led to postwar industrial expansion. Finland's break can be explained by its independence from the Soviet Union in 1920 and the subsequent civil war. The United Kingdom's break occurs in 1928, shortly after a wave of strikes culminated in the general strike of 1926.
Sweden is one of two countries where the unit root can not be rejected. What separates Sweden from the rest of the world is its longtime political neutrality. During World War II, Sweden was the only Scandinavian country to succeed in remaining neutral, and emerged from both wars virtually undamaged. Its break date of 1926 can be explained by the widespread unemployment during the recession in the 1920s.

Since univariate unit root tests suffer from low statistical power in finite samples, which may lead to failures in rejecting a false null hypothesis, Quah address this issue, by applying panel unit root tests that have significantly increased power to test for convergence. In particular, Quah (1992) considers the following simple dynamic model to improve the power of the univariate Dickey-Fuller procedures:

$$(y_{i,t} - \bar{y}_t) = r(y_{i,t-1} - \bar{y}_{t-1}) + e_{i,t} \quad (56)$$

where $y_{i,t} - \bar{y}_t$ is the income disparity from mean output, or from the benchmark economy of i = 1,…,N countries at time t. Quah studies the presence of common stochastic trends in a large cross section of aggregate economies. He does this by subtracting US per capita output from the per capita output of every economy under study, and then examines if unit roots remain in the resulting series. Because the number of time-series observations is the same order of magnitude as the number of countries, random-field asymptotics are used to compute significance levels. Quah suggests a pooled ordinary-least-squares estimation, in which values of ρ less than 1 indicate that disparity from the mean is decreasing with time. He shows that this statistic converges weakly to N(0,1) as the number of countries and sample size get large.

He rejects the null hypothesis of no unit roots in the per capita output difference series, providing evidence against convergence to US output. In other words, he finds evidence against convergence, in the sense given by the equation (48). Nevertheless, it is inherently a test of whether a set of series have converged, and can not address the issue of whether such series are in the process of converging.

Levin and Lin (1993) provide a general testing framework, by considering the following three models:

$$\Delta\left(y_{i,t} - \bar{y}_t\right) = r\left(y_{i,t-1} - \bar{y}_{t-1}\right) + a_{m,i} d_{m,t} + e_{i,t} \quad (57)$$

for m = 1,2,3 and where $d_{m,t}$ contains deterministic variables, namely, $d_{1,t}$={·}, $d_{2,t}$={1}, $d_{3,t}$={1,t}. They improve on Quah's method by including fixed effects and individual time trends for each country. Such a framework allows both different steady-states for the variable $y_{i,t}$ and different time trends for each country. After establishing that asymptotics of their statistics converge weakly to N(0,1) under the null hypothesis, these authors illustrate that the no convergence hypothesis, namely ρ=0, can be tested against the alternative hypothesis of income disparities dampening over time, ρ<0.

Both the Quah and Levin and Lin tests, assume that ρ, and hence the convergence rate (1-ρ), is the same for all countries in each group. This homogeneity assumption requires all countries within each group to share a common average speed of adjustment to steady-state equilibria in all variables. Hence, only inference about convergence rate of the whole group can be drawn. Therefore, this approach provides a natural and appealing technique for comparing the behavior of the cross-section of countries over time.

Im, Pesaran and Shin (2003) relax the assumption of homogeneity in convergence rates because of potential bias in heterogeneous panels. Therefore, their test does not impose identical convergence rates and consequently avoids possible misspecification of the model, which may lead to false inference. Their method pools N separate independent Augmented Dickey-Fuller regressions:

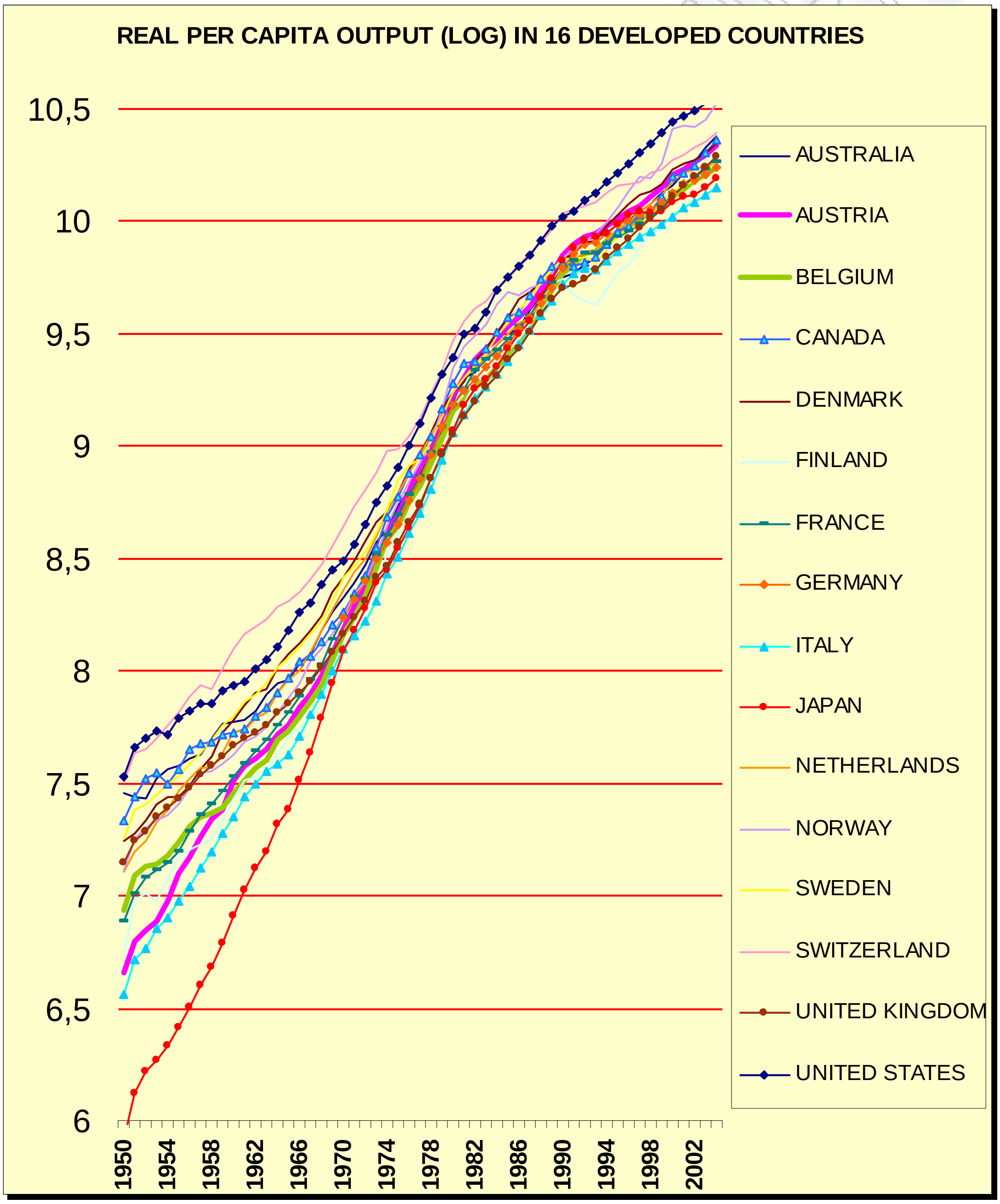
$$\Delta\left(y_{i,t} - \bar{y}_t\right) = d_i + r_i\left(y_{i,t-1} - \bar{y}_{t-1}\right) + \sum_{k=1}^{p} f_{i,k}\Delta\left(y_{i,t-k} - \bar{y}_{t-k}\right) + u_{i,t} \quad (58)$$

This procedure allows for heterogeneity in ρ by testing the null hypothesis, $r_i$=0 for all I, against the alternative hypothesis, $r_i$<0 for at least one i. The limiting distribution for their t-statistic is given as

$$\sqrt{N}\,\frac{\left(\bar{t}_{ADF} - m_{ADF}\right)}{\sqrt{s^2_{ADF}}} \quad (59)$$

where the moments $m_{ADF}$ and $s^2_{ADF}$ are obtained from Monte Carlo simulations, and $\bar{t}_{ADF}$ is the average estimated ADF t-statistics from the sample. Not only does the Im, Pesaran and Shin test have significantly greater power compared to Levin and Lin test, especially when the number of countries is small, but it also has better size properties when the choice of the ADF order is misspecified. Nevertheless, Levin and Lin as well as Im, Pesaran and Shin techniques share the common assumption of an identically and independently distributed error structure. When this assumption is violated and residuals are contemporaneously correlated, both techniques suffer from significant size distortions that do not disappear by simple demeaning.

**Figure 3**



Ben-David (1995) has applied the following test in a number of papers. The test involves the estimation of φ in the following equation

$$\log y_{n,t} - \log \bar{y}_t = f\left(\log y_{n,t-1} - \log \bar{y}_{t-1}\right) \quad (60)$$

where φ is a parameter, $\log y_{n,t}$ is the logarithm of per capita output for economy n and $\log \bar{y}_t$ is the mean across the sample economies. If the estimate of parameter φ < 0, then economy n's output per capita approaches the sample mean, indicating convergence. The advantage of this approach lies in clarity, simplicity and applicability to each economy on the sample. Moreover, one can identify the convergers as well as non-convergers.

Bernard and Durlauf (1995, 1996) were the first to define cross-country output convergence in terms of the limit of expected output gaps, implied by the equation (48). Based on this definition, they propose testing for cross-country convergence using cointegration techniques. In their empirical application they consider output series from 15 OECD countries over the period 1900-1987 and apply multi-variate cointegration techniques to all the 15 series, a subset of 11 European series and a smaller subset of six European series. The cointegration tests are applied to all the individual output series as well as to output deviations computed with respect to the U.S. output for the 15 OECD sample, and with respect to French output for the two subsamples. Overall, the convergence hypothesis is rejected. Nevertheless, a key implication can be illustrated, typified by Bernard and Durlauf. In addition to applying these procedures, analysis is restricted to particular subgroups of economies, for instance the OECD. Multivariate unit root and cointegration tests reject the null hypothesis that there is a single unit root process driving output across the OECD economies. Thus, across all the economies in the OECD grouping, time-series forecast convergence can be rejected. At the same time, however, individual country pairs – for instance Belgium and the Netherlands – do display such convergence.

According to Hall, Robertson and Wickens (1997) cointegration is not necessary for convergence as it is possible to construct series that are not cointegrated yet converge. For example, two series that differ by a random walk for t<T and are identical thereafter will converge in probability, and indeed pointwise, yet are not cointegrated. This brings out an important difference between the concepts of convergence and cointegration. Convergence is determined by the limiting (large t) behaviour of the series, while cointegration is a property of the entire time history of the series. Therefore, in constructing a test for convergence it is important to take account of the distinction between convergence and cointegration.

Hobijn and Franses (2000) find little evidence of convergence across 112 countries taken from the Penn World Table for the period

1960-1989. Their survey consists an important contribution to identifying convergence clubs using time series methods. In particular, they employ a clustering algorithm to identify groups of converging countries. Their algorithm finds many small clusters in their sample of 112 countries. Depending on the particular rule used to determine cluster membership, they find 42 or 63 clusters with most containing just two or three countries. Hobijn and Franses view these clusters as convergence clubs but it is not clear that they represent groups of countries in distinct basins of attraction of the growth process. Absent controls for structural characteristics, these groupings could simply reflect the pattern of differences in those characteristics rather than differences in long-run outcomes due to differences in initial conditions. Moreover, the argument about the substantive economic assumptions that underlie time series methods for studying convergence seems applicable. Given the breadth of the sample used by Hobijn and Franses, it is unlikely that it contains only data generated by countries whose behavior is near their respective steady-states. Such an assumption is much more plausible for restricted samples as the OECD countries. The clusters they find could thus reflect, in many cases at least, transition dynamics rather than convergence clubs.

Koukouritakis and Michelis (2002) analyzed the long run cointegration properties of real per capita GDPs among the 10 new countries and the 3 E.M.U. countries, France, Germany and the Netherlands. They viewed evidence of the long run co-movements in real per capita GDPs as strengthening the case for successful E.M.U. enlargement by some or all the new countries.

Pesaran (2007) employs convergence definitions that explicitly focus on the probability of large deviations, i.e. equation (23). In particular, he applies a pair-wise approach to output series using both Penn World Table (PWTs) and Maddison data sets over the 1950-2000 period. In this framework, to analyze output convergence across different countries in a global context, as well as in specific geographical regions, without being subject to the pitfalls that surround the use of output gaps measured relative to a particular country benchmark, Pesaran examines the unit root and trending properties of all N(N-1)/2 possible log real per capita output gaps, $y_{i,t} - y_{j,t}$. In addition, the pair-wise approach has the added advantage that it relates more naturally to the club convergence literature. Overall, Pesaran has found little evidence of log per capita output convergence at a global level. For example, using PWT data over the period 1961-2000, the unit root hypothesis was rejected at most in the case of 370 out of 4851 possible output gap pairs, just around 7.6%, which is very close to the nominal significance level of 5% used for the test.

Ultimately, time series approaches to convergence are subject to a major weakness. More specifically, convergence is tested under a statistical analysis which requires that the data under consideration must be generated by a time-invariant data generating process. However, if economies are in transition towards steady state, their associated per capita output series will not satisfy this property.

At this point, it is worthy of note some key incompatibilities between cross-section and time series tests. Time-series and cross-section approaches to convergence make different assumptions both about what one means by convergence and about the properties of the economies under study, and therefore how tests within the two frameworks can lead to very different conclusions concerning cross-country output relationship. At one level, if the two types of tests are applied to the same data set, they must necessarily be inconsistent and in practice the two approaches commonly provide conflicting evidence. This holds because, time series approach to convergence, by requiring that output differences be zero-mean and stationary, requires a condition inconsistent with that implied in cross-section regressions, namely that the difference between a rich and poor economy have a nonzero mean.

More specifically, under cross-section tests, convergence requires that the expected value of $g_{i,T} - g_{j,T} = T^{-1}\sum_{t=1}^{T}\Delta y_{i,t} - T^{-1}\sum_{t=1}^{T}\Delta y_{j,t}$ is negative if $y_{i,0} - y_{j,0}$ is positive whereas under time series tests, convergence requires that the expected value of $g_{i,T} - g_{j,T} = T^{-1}\sum_{t=1}^{T}\Delta y_{i,t} - T^{-1}\sum_{t=1}^{T}\Delta y_{j,t}$ is zero regardless of the value of $y_{i,0} - y_{j,0}$. Thus, there exists a set of values for the sample moments of $\Delta y_{i,t}$ and $\Delta y_{j,t}$ which implies convergence under one test yet implies no convergence under the other.

Moreover, there is an apparent dissimilarity in the data restrictions that the two approaches to convergence require. This point is easy to understand provided that we observe that the two approaches to convergence have fundamentally different views with respect to the properties of the data under their analysis. To be exact, in cross-section tests, one assumes that the data are in transition towards a limiting distribution and convergence is interpreted as meaning that initial output differences between economies diminish over a fixed time period. In time series tests, one assumes that the data are generated by economies near their limiting distributions and convergence is interpreted to mean that initial conditions have no statistically significant effect on the expected value of output differences. As a result, a given approach is appropriate depending upon whether one regards the data as better characterized by transition or steady state dynamics.

Further, if the data are taken from economies which are far from their steady states, then the sample moments of the data might inaccurately approximate the limiting population moments. For example, per capita output for an economy at a unique steady state will strictly exceed output of an economy converging to the same steady state from below. Hence the mean of the first economy will be strictly greater than the second, which violates equation (48) when sample means are used to proxy for asymptotic means. In such a situation, the null of no convergence may be erroneously accepted when time series tests are used. In other words, time series tests may have poor power properties when applied to data from economies in transition.

As a result, cross section tests appear to more naturally apply to transition data whereas time series tests appear to more naturally apply to data whose sample moments well approximate the properties of the limiting distribution of the economies under study. Quah (1993b) empirically support this distinction. In particular, Quah indicates that the instability of mean growth rates over different subsamples for countries illustrates how for this large cross-section, the data fail to possess the invariant moments necessary for time series analysis.

Ultimately, time series tests turn out to place much stronger restrictions on the behaviour of growth across countries than the associated cross-section tests. As a result, the cross-section tests can reject a no convergence null hypothesis for data generated by economies with different long run steady states. Time series do not spuriously reject the null hypothesis of no convergence for data generated by multiple long run equilibria. However, the time series approach requires that the economies under analysis are near their long run equilibria since the tests assume that the sample moments of the data accurately approximate the limiting moments for the data under analysis. Therefore, time series tests can give misleading inferences if the data are largely driven by transition dynamics. Overall, the results suggest that neither testing framework is likely to yield unambiguous conclusions.

A distinct line of criticism of time series convergence tests is due to the validity of unit root tests in the presence of structural breaks in $\log y_{i,t} - \log_{j,t}$. Perron (1989) is the first who argued that testing for unit roots can lead to spurious evidence in support of the null hypothesis that a unit root is present because of the researcher's failure to allow for structural breaks. Greasley and Oxley (1997) initially introduced such an analysis, by imposing breaks exogenously in cross-country contexts. As expected, their findings indicate results somewhat different compared to that of Bernard and Durlauf, i.e. Greasley and Oxley find convergence for Denmark and Sweden whereas the sort of test employed by Bernard and Durlauf (1996) does not. Moreover, Li and Papell (1999) systematically studied the role of breaks in time series convergence. An important feature of their analysis is that they avoid exogenous imposition of trend breaks (in fact, they endogenise the break date selection) and, as stated above, they find that the dates of these breaks exhibit some heterogeneity, although many of them cluster around World War II. According to Li and Papell, allowing for trend breaks reduces the number of country pairs that fail to exhibit convergence. Therefore, evidence for convergence i.e. for the OECD countries is more mixed compared to that derived by test that fail to allow for trend breaks. These findings are confirmed by Carlino and Mills (1993) who, as stated above, study U.S. regions and reject convergence except under specifications that allow for a trend break in 1946.

It is indisputable that the introduction of trend breaks to time series convergence tests is valuable because of its implications about the time series structure of output differences between countries. Nevertheless, the weakness of such studies is that they suffer from interpretation problems. The presence of the regime break is indicative of an absence of convergence in the sense implied by equation (20) or (48), because it suggests that there is some component of $\log y_{i,t} - \log y_{j,t}$ that will not disappear over a sufficiently long time horizon. Thus, by any long-term predictability in output differences, the time series definition of convergence is violated. However, the sort of violation of equation (20) or (48) implied by a trend break is different from the type implied by a unit root. To be exact, a break associated with the level of output means that the output difference between two countries is always bounded, unlike the unit root case. Therefore, the evidence of convergence that is supported by some researchers who allow for data breaks sets the question of what is meant by convergence.

However, an alternative explanation of the failure to find considerable evidence of convergence might be that the per capita output series are not I(1), but rather fractionally integrated. A series is said to be fractionally integrated, or FI(d), if it is integrated of order d, with d not necessarily integer. When d=0, any shock that affects the series has only a short-term effect, which completely disappears in the long run. In this case, the series is said to be “short memory”. On the contrary, when d>0, the value of the series will somehow be influenced by shocks that took place in the very remote past. In this case, the series exhibit “long memory” or “persistence”. The intensity of memory of the series will depend on the value of d: the smaller d, the less persistent will be the shocks. If d<0.5, the series is however stationary. A very interesting case for many economic issues is when 0.5<d<1. In this situation, the series is long memory and non-stationary although mean-reverting: in spite of the fact that remote shocks affect the present value of the series, this will tend to its mean value in the long run. In other words, the series has long but transitory memory. This is quite distinct from the case d≥1 in which the mean of the series has no influence whatsoever on the long run evolution of it, because the series is dominated by all the remote and recent shocks. In this case, the series has permanent or infinite memory. So, provided d<1, some sort of a long run equilibrium level of the series exists which is represented by the mean. Obviously, when 0<d<1, traditional unit root tests (testing d=1 under the null hypothesis) or stationarity tests (testing d=0 under the null hypothesis) may fail to detect mean-reversion in the series and reach the wrong conclusion of infinite memory.

Other problems occur when the series are FI(d) but are treated as if they were I(1). Traditional cointegration tests between two or more series are flawed not only because d differs from 1, but also because traditional cointegration is based on the assumption that all the possibly cointegrated series have the same order of integration, which is very difficult to guarantee when d may take non-integer values.

An alternative approach in the time series context has been first proposed by Michelacci and Zaffaroni (2000). These authors detect possible theoretical contradictions in the coexistence of I(1) outputs and β-convergence. They then show that there are theoretical reasons why the output levels series should be fractionally integrated and that mean-reverting fractional integration of output levels – i.e. output levels being FI(0.5.<d<1) – is compatible with the empirical results of the β-convergence regression reported in the literature. They then redefine the β-convergence concept in terms of mean reversion of the deviations of output levels around a country-specific or a common trend, instead of defining it in terms of trend stationarity of output differentials. Specifically, they propose the following definition of (absence of) β-convergence: “an economy has no tendency to converge either towards its own or the common steady state if, after fitting either a country specific or a common (linear) trend respectively, the parameter of fractional integration d of the residuals is greater than or equal to 1 (d≥1). In the former case we say that there is no conditional convergence and in the latter that there is no unconditional convergence. They then test the integration order of the residuals of their definition and conclude that these residuals are indeed FID(0<d<1), which agrees with their new definition of convergence. Ultimately, by offering theoretical and empirical evidence of fractional integration of output levels, Michelacci and Zaffaroni made an important contribution towards the solving of the puzzling results of no convergence usually obtained in the time series context. In particular, their results indicate that all the tests based on the assumption of the output being I(1) and searching for an I(0) differential or for traditional C(1,1) cointegration between output levels are invalid.

# 10 METHODOLOGY

In order to test convergence, we apply two advanced tests, suggested by Pesaran (2007) and Michelis & Christou (2007). In this section, we explicitly present the principal steps and the methodology that we use in order to apply both tests.

## 10.1 PESARAN: PAIR-WISE APPROACH

Formal tests of cross-country convergence can be developed by focusing on pair-wise output gaps. Application of unit-root tests to output gaps measured with respect to a reference country is more practical, but is not invariant to the choice of the benchmark country and as a result can lead to misleading conclusions.

To analyze output convergence across a large number of countries without being subject to the pitfalls that surround the use of output gaps measured relative to a particular country benchmark, Pesaran considers the following approach: a pair-wise approach that considers the unit-root and trending properties of all N(N-1)/2 possible log real per-capita output gaps, $y_{i,t} - y_{j,t}$, i = 1,…,N-1, and j = i+1,…,N.

As compared to cross-section or panel techniques used for the analysis of convergence, the pair-wise approach has the added advantage that it is more informative for investigating the hypothesis of "club convergence" and allows for the possibility of forming country clusters (if any) from the test outcomes. However, special care must be taken in dealing with the specification search bias that such a strategy would entail.

In particular, we consider any two countries, i and j, and denote their log per capita output gap as $d_{i,j,t} = y_{i,t} - y_{j,t}$. As we have defined above, two countries are output convergent if $d_{i,j,t} = y_{i,t} - y_{j,t}$ is an I(0) process with a constant mean. Accordingly, Pesaran applies ADF test to investigate the unit root and trending properties of all N(N-1)/2 possible log real per capita output gaps $d_{i,j,t} = y_{i,t} - y_{j,t}$, i = 1,…,N-1, and j = i+1,…,N. In particular, Pesaran run a regression on the first difference of the log real per capita output gaps on a constant, a trend, the lagged level of log real per capita output gaps and $k_{i,j}$ lagged first differences of log real per capita output gaps.

$$\Delta d_{i,j,t} = a_{i,j} + b_{i,j} t + g_{i,j} d_{i,j,t-1} + \sum_{p=1}^{k} d_{i,j,p} \Delta d_{i,j,t-p} + e_{i,j,t} \qquad (61)$$

The order of the ADF regressions, $k_{i,j}$, can be chosen using model selection criteria. In our empirical application we report test results for order of the ADF regressions, $k_{i,j}$, selected using the Akaike Information Criterion (AIC).

The ADF statistic tests the null of divergence. Thus, in the first stage, we apply ADF test to investigate the presence of unit root. If $|g_{i,j}|$ is not significantly different from zero, there is evidence of presence of unit root, implying that shocks to log real per capita output gaps are permanent and this pair of countries does not converge. Otherwise, if $|g_{i,j}|$ is significantly different from zero, the unit root null can be rejected, implying that shocks to log real per capita output gaps will be temporary. In the second stage, if the unit root hypothesis is rejected, we consider testing the hypothesis that $d_{i,j,t} = y_{i,t} - y_{j,t}$ is not trended. If $|b_{i,t}|$ is significantly different from zero, then it implies that the per capita output differential $d_{i,j,t} = y_{i,t} - y_{j,t}$ is trend stationary, a condition which is not sufficient for real convergence. Otherwise, if $|b_{i,t}|$ is not significantly different from zero, then it implies the per capita output differential $d_{i,j,t} = y_{i,t} - y_{j,t}$ is stationary around a constant level. Therefore, we conclude that each pair of countries is output convergent in the case that we can reject the presence of unit root and simultaneously the per capita output differential is level stationary.

## 10.2 MICHELIS & CHRISTOU: ROLLING REGRESSIONS

It is widely identified that traditional tests for the presence of cointegration over the entire sample period tend to reject the hypothesis that the output series are cointegrated if the extent of cointegration changes over time. Since the change is gradual, a system of variables that is moving from an uncointegrated state to one that is characterized by the existence of cointegration suggests that the underlying probability law is in flux because either its parameters or stochastic properties are changing. Consequently, to deal with the possibility of gradually time-varying cointegration, it is proposed an alternative technique that explicitly allows for changes in the relationship between a system of variables, known as rolling cointegration.

We use the technique of rolling cointegration to obtain time-varying estimates of the convergence of a set of countries, i.e. EU15. If the EU14 countries were in the process converging with France, then a test for convergence having been achieved over the entire sample, such as provided by conventional tests for cointegration, would be biased toward rejecting cointegration and thus convergence. We overcome this possibility by using rolling cointegration tests that explicitly take into account the possibility that the data series are (more) cointegrated during some parts of the sample period but less so or not at all during other parts. Moreover, the use of rolling cointegration allow us to use a longer time period and to test for evidence of cointegration early on in the transition without fear that these early data will bias tests for cointegration later years.

In order to analyze convergence, we need to examine both the (deterministic) trending properties of output differentials and the unit root properties of output differentials. However, we are subject to an important hindrance. To be exact, in this procedure we seek reliable inference about the deterministic trend in the presence of uncertainty about the unit root while we simultaneously seek reliable inference about unit root in the presence of uncertainty about the deterministic trend.

To deal with this hindrance, an alternative approach is suggested by Michelis and Christou (2007). In particular, they offer a rolling time series convergence strategy. We explicitly present the main steps of this strategy below:

**Step 1**:

Select the benchmark $y_t^*$ and calculate the output differential $d_{i,t} = y_t^* - y_{i,t}$

**Step 2**:
Select the Rolling Window and the Rolling Step

**Step 3**:
Calculate the size, the finite sample critical values for a number of unit root tests

**Step 4**:
In every rolling window: Select the best unit root test for the differentials $d_{i,t} = y_t^* - y_{i,t}$

a) Fit an ARMA model to the differentials $d_{i,t} = y_t^* - y_{i,t}$
b) Use the estimated model as a Data Generating Process
c) Calculate the (size-adjusted) power for a number of unit root tests
d) Select the best unit root test (in terms of power) for the data at hand

**Step 5**:
In every rolling window, use sequential strategy, suggested by Ayat and Burridge (2000), to test for the existence of stochastic and/or deterministic trends in the differential $d_{i,t} = y_t^* - y_{i,t}$.

Further, we explicitly present the main steps of the sequential testing

**Step 1**:
Perform a preliminary unit root test invariant to linear trend under the null hypothesis.

**Step 2a**:
If the unit root is not rejected at step 1, provisionally maintain this hypothesis and estimate

$$\Delta y_t = b_1 + \sum_{j=1}^{p} a_j \Delta y_{t-j} + e_t$$

testing for the null that there is no linear trend using the test statistic on $b_1$ referred to standard tables.

**Step 2b**:
If the unit root is rejected at step 1, test for the null that there is no linear trend using the t-statistic on $b_1$ in $\Delta y_t = (r-1) y_{t-1} + b_0 + b_1 t + \sum_{j=1}^{p} a_j \Delta y_{t-j} + e_t$ , referred to standard tables.

**Step 3a**:
If the null "no linear trend" was rejected at step2, stop, since the unit root test already conducted is the only one available which is invariant to the maintained linear trend.

**Step 3b**:
If the null "no linear trend" was not rejected at step2, perform a second provisional unit root test invariant to the mean under the null.

**Step 4a**:
If the unit root is rejected at step (3b), stop.

**Step 4b**:
If the unit root is not rejected at step (3b), test the magnitude of the initial observation, $y_1$, relative to the increments in $y$ using $y_1/\sqrt{\{T^{-1}\sum(\Delta y_t)^2\}}$ referred to $N(0,1)$.

**Step 5a**:
If $y_1$ differs significantly from zero, stop.

**Step 5b**:
If $y_1$ does not differ significantly from zero, perform a unit root test which is not invariant to the mean under the null.

## 11. EMPIRICAL EVIDENCE

We have already mentioned the most dominant techniques, which are used to test convergence, by presenting their methodology and the criticism that they accept. We pay particularly attention to two tests, which we consider to be the most appropriate to examine convergence. In this section, we present the results that we received, by applying these two tests. Before we quote the results, it is necessary to present some of the substantial characteristics of the research with respect to the data that we use in order to apply the tests.

## 11.1 DATA

Primary sources of data are the annual output series from the Penn World Table (PWT) that span from 1950 to 2004. In this study we report both the pair-wise and the rolling regression test results using the purchasing power parity adjusted real GDP per capita in constant prices from the most recent Version 6.2 of PWT. Real GDP per capita is constructed in international dollars, with 2000 as the reference year. We use log per capita output gaps that concern different countries in a global context, as well as in specific group of countries. The list of countries (by groups) combined with the sample periods are provided in Table 1.

The pair-wise test was carried out at the 10% significance level for the N(N-1)/2 distinct pairs of $y_{i,t} - y_{j,t}$, $i \neq j$. The most PWT series begin in 1950, but we consider three sample periods: 1950-2004 (Sub-sample 1), 1960-2004 (Sub-sample 2), 1970-2004(Sub-sample 3). However, we point out that due to lack of data availability for some countries, the sub-sample 1 for EU14 is 1951-2004, for OECD25 is 1953-2004 and for the group characterized as “All Countries” is 1955-2004. In addition, we stress that Germany’s data is available only after 1970 and for this reason Germany is excluded from the countries depicted in Table 1. However, we report results for EU15 and OECD16, included Germany, for the Sub-sample 3 period.

The rolling regression test was carried out at the 10% significance level, selecting the rolling window to be 30 years and the rolling step to be 1 year. The rolling regression was applied for the following groups: G6, EU14, OECD15 and OECD25. In each group, we use as benchmark the average of the group, in an effort to examine whether club convergence exists or not. In addition, we use as benchmark the United States for the cases of G6, OECD15 and OECD25, as the United States is the largest economy in the world and it is the country traditionally used for this purpose in the convergence literature. We point out that in the case of EU, Germany is excluded because of the lack of data availability and it is not used as a benchmark because Germany experienced considerable monetary and real turbulence in the early and mid-1990s due to the difficulties encountered in the reunification of the country. Consequently, in the case of EU, we use as benchmark France, as it did not experience the reunification shocks that Germany did and it may serve as a more stable indicator of EU policies and performance.

**Table 1**
Composition of country groups for the different sample periods in the PWT

| Country Group | Composition |
|---|---|
| Sample period: 1950 - 2004 | |
| Group: G6 | Canada, France, Italy, Japan, United Kingdom, United States |
| | |
| Sample period: 1951 - 2004 | |
| Group: EU14 | Austria, Belgium, Denmark, Finland, France, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden, United Kingdom |
| | |
| Sample period: 1950 – 2004 | |
| Group: OECD15 | Australia, Austria, Belgium, Canada, Denmark, Finland, France, Italy, Japan, Netherlands, Norway, Sweden, Switzerland, United Kingdom, United States |
| | |
| Sample period: 1953 - 2004 | |
| Group: OECD25 | Australia, Austria, Belgium, Canada, Denmark, Finland, France, Greece, Iceland, Ireland, Italy, Japan, Korea, Luxembourg, Mexico, Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, United Kingdom, United States |
| | |
| Sample period: 1955 - 2004 | |
| Group: ALL COUNTRIES | Argentina, Australia, Austria, Belgium, Bolivia, Canada, Chile, China, Colombia, Costa Rica, Denmark, Ecuador, Finland, France, Greece, Guatemala, Iceland, India, Iran, Ireland, Israel, Italy, Japan, Jordan, Korea, Luxembourg, Malaysia, Mauritius, Mexico, Morocco, Netherlands, New Zealand, Norway, Peru, Philippines, Portugal, South Africa, Spain, Sweden, Switzerland, Thailand, Turkey, United Kingdom, United States |

## 11.2 RESULTS FROM PAIR-WISE APPROACH

We begin by considering the unit root properties of all output gap pairs, $y_{i,t} - y_{j,t}$, in the world economy, represented by the group "all countries", over the three sample periods 1950-2004 (Sub-sample 1), 1960-2004 (Sub-sample 2) and 1970-2004 (Sub-sample 3). For each output gap series we consider the unit root and trending properties. The results for all the possible output gap pairs are summarized in Table 2, for the three sample periods. Table 2 reports the proportions of the output gap pairs (i) for which the unit root hypothesis is rejected and (ii) with insignificant linear trend coefficients, at 10% significance levels, for the different sampling periods, using the testing procedure set out above. Overall, the results do not support the output convergence hypothesis at a global level. The proportion of output gap pairs that meet both criteria and can be viewed as being stationary with a constant mean are very small. In fact, they are even below the significance level of the ADF test in every sub-sample period and in no case exceed 7.82% of the total number of possible output gap pairs. Despite a small increase in the proportion of output gap pairs that support convergence in the sub-sample 2 period, there is a decrease in the sub-sample 3 period that brought this proportion of output gap pairs even below the proportion of those in sub-sample 1 period.

**Table 2**
Proportion of output gap pairs (i) for which the unit-root hypothesis is rejected and (ii) with insignificant linear trend coefficients, at the 10% significance level – PWT series

| GROUPS | Sub-sample 1 (1950-2004) | Sub-sample 2 (1960-2004) | Sub-sample 3 (1970-2004) |
|---|---|---|---|
| G6 | 6.67% | 6.67% | 13.33% |
| EU14 | 4.40% | 8.79% | 16.48% |
| OECD15 | 8.57% | 9.52% | 14.29% |
| OECD25 | 6.33% | 8.00% | 12.33% |
| ALL COUNTRIES | 6.98% | 7.82% | 6.87% |

Although, we have found little evidence of log per capita output convergence at a global level, there seems to be some evidence of club convergence, so long as the concept of a “club” is loosely defined to mean countries with pair-wise output gaps that are stationary with a constant mean. This concept does not, of course, rule out the possibility of the club membership to change over time. Nevertheless, the proportion of output gap pairs that meet both the unit-root and the cotrending tests is very close to the chosen significance level for all country groups. In particular, for all country groups this proportion is even below the 10% significance level with respect to sub-sample 1 period and sub-sample 2 period. Only in the sub-sample 3 period is the proportion for all country groups above the 10% significance level, but at the best case (EU14) is only just 16.48%. While EU14 had the lowest proportion of stationary output gap pairs over the period 1950-2004, it turned out to have the highest proportion in the last sub-sample period. Moreover, the proportion of output gap pairs that support the convergence hypothesis is increasing over time with respect to OECD15 and OECD25. In fact, the proportion of OECD15 is always higher than that of OECD25. We point out that if we include Germany, the proportion of output gap pairs that can be viewed as being stationary around a constant mean is 19.05% for the EU15 and 15.83% for OECD16 over the period 1970-2004. Further, G6 presents the more stable proportion across the different country groupings. However, these differences need to be viewed with caution, since the number of countries in the country groupings differ markedly.

Overall, the results do not support the output convergence hypothesis and suggest that the identification of club convergence by some investigators might be due to chance, not to mention the usual sample selection biases associated with statistical grouping procedures often used in the literature. Furthermore, even if one accepts that such convergence clubs exist, their membership tends to undergo important changes over time. The main reason for this non-convergent result seems to be the existence of country-specific unobserved factors that tend to be highly persistent. Non-convergence of log per capita outputs suggests that while common technological progress seems to have been diffusing reasonably widely across economies, there are nevertheless important country-specific factors (for example, wars, famines, revolutions, regime and institutional changes) that render output gaps highly persistent, such that we cannot be sure that the probability for the output gaps to lie within a fixed range will be non-zero.

## 11.3 RESULTS FROM ROLLING REGRESSIONS

In this section we the results that we receive by utilizing the technique of rolling regression to obtain time-varying estimates of the convergence of real per capita income in selected group of interest such as G6, EU14, OECD15 and OECD25. As we stated above, if the countries in the selected groups were in the process converging with the selected benchmark, then a test for convergence having been achieved over the entire sample, such as provided by conventional tests for cointegration, would be biased toward rejecting cointegration and thus convergence. We overcome this possibility by using rolling regression test that explicitly take into account the possibility that the data series are (more) cointegrated during some parts of the sample period but less so or not all during other parts. Moreover, the use of rolling cointegration allows us to use a longer time period and to test for evidence of cointegration early on in the transition without fear that these early data will bias test for cointegration later years.

We use the rolling regression test to investigate the degree of convergence during different sub-sample periods of the full sample. In particular, the rolling regression tests are conducted, following the steps that we set out above and rolling annually 30-year sub-samples. For example, the first test statistic is obtained from the beginning of the sample period through to the 30$^{th}$ observation, i.e. 1950-1980. The next test statistic is obtained by using data from the second observation through to the 31$^{th}$ observation, and so on until the last observation is used. Using a bivariate approach, the tests are applied to the real per capita incomes of each country of a selected group and of its benchmark. Of course, finding a single 30 year sample for which we accept that the series are cointegrated is not strong evidence of cointegration. Rather, what we seek is a large number of contiguous 30 year samples for which we can accept the hypothesis of cointegration.

Overall, the results do not support the output convergence hypothesis, as we find very little evidence of log per capita output convergence in the vast majority of output gaps. The results of the rolling regression tests for output convergence are reported in Tables 3-10. The first two tables concerns with G6 countries. To be exact, Table 3 shows the significance test for output convergence between the United States series and those of the rest countries of G6. Table 4 provides the same information but with the average of G6 countries rather than the United States as the benchmark. In the case that we select the average of G6 countries as benchmark, we are not able to reject the hypothesis of no convergence between all the possible output gap series at the 10% significance level for almost all the specified sub-samples. In the case that we use as benchmark the United States, the results differ only for the case of United Kingdom. Although there are

**Table 3**

Rolling Regression Test of real per capita GDP between the United States and G6 countries

| | FRANCE | JAPAN | CANADA | ITALY | UNITED KINGDOM |
|---|---|---|---|---|---|
| 1950 - 1980 | NO | NO | NO | NO | NO |
| 1951 - 1981 | NO | NO | NO | NO | NO |
| 1952 - 1982 | NO | NO | NO | NO | YES |
| 1953 - 1983 | NO | NO | NO | NO | NO |
| 1954 - 1984 | NO | NO | NO | NO | NO |
| 1955 - 1985 | NO | NO | NO | NO | YES |
| 1956 - 1986 | NO | NO | NO | YES | NO |
| 1957 - 1987 | NO | NO | NO | YES | YES |
| 1958 - 1988 | NO | NO | NO | NO | NO |
| 1959 - 1989 | NO | NO | NO | NO | NO |
| 1960 - 1990 | NO | NO | NO | NO | NO |
| 1961 - 1991 | NO | NO | NO | NO | NO |
| 1962 - 1992 | NO | NO | NO | NO | NO |
| 1963 - 1993 | NO | NO | NO | NO | NO |
| 1964 - 1994 | NO | NO | NO | NO | NO |
| 1965 - 1995 | NO | NO | NO | NO | NO |
| 1966 - 1996 | NO | NO | NO | NO | NO |
| 1967 - 1997 | NO | NO | NO | NO | NO |
| 1968 - 1998 | NO | NO | NO | NO | NO |
| 1969 - 1999 | NO | NO | NO | NO | YES |
| 1970 - 2000 | NO | NO | NO | NO | NO |
| 1971 - 2001 | NO | NO | NO | NO | YES |
| 1972 - 2002 | NO | NO | NO | NO | YES |
| 1973 - 2003 | NO | NO | NO | NO | YES |
| 1974 - 2004 | YES | NO | NO | NO | YES |

three sub-samples, though not contiguous, at the beginning of the sample period, there is clear evidence of convergence between the United States and United Kingdom at the end of the sample period, as we can reject the hypothesis that there is no convergence for the last five out of six 30-year sub-sample periods ending between 1999 and 2004 (the test statistic is reported on the last year of the rolling 30-year sample period from which it is derived). As far as the rest countries are concerned, we can not reject the hypothesis of no convergence in almost all 30-year sub-sample periods. There are two contiguous sub-sample periods ending in 1986 and 1987, in which we can reject the hypothesis of no convergence between Italy and the United States. Nevertheless, this evidence is not sufficient to support convergence between these two countries, as a larger number of contiguous 30-year sub-samples is needed.

Moreover, Table 5 provides the significance tests for per capita GDP convergence between the United States and the countries of OECD15, while Table 6 reports the same information with the average of OECD15 countries as the benchmark. Overall, the results do not

**Table 4**

Rolling Regression Test of real per capita GDP between G6 countries and the average of G6 countries

| | UNITED STATES | FRANCE | JAPAN | CANADA | ITALY | UNITED KINGDOM |
|---|---|---|---|---|---|---|
| 1950 - 1980 | NO | NO | NO | NO | NO | NO |
| 1951 - 1981 | NO | NO | NO | NO | NO | NO |
| 1952 - 1982 | NO | NO | NO | NO | NO | NO |
| 1953 - 1983 | NO | NO | NO | NO | NO | NO |
| 1954 - 1984 | NO | NO | NO | NO | NO | NO |
| 1955 - 1985 | NO | NO | NO | NO | NO | NO |
| 1956 - 1986 | NO | NO | NO | NO | NO | NO |
| 1957 - 1987 | NO | YES | NO | NO | NO | NO |
| 1958 - 1988 | NO | NO | NO | NO | NO | NO |
| 1959 - 1989 | NO | NO | NO | NO | NO | NO |
| 1960 - 1990 | NO | NO | YES | NO | NO | NO |
| 1961 - 1991 | NO | NO | NO | NO | NO | NO |
| 1962 - 1992 | NO | NO | NO | NO | NO | NO |
| 1963 - 1993 | NO | NO | NO | NO | NO | NO |
| 1964 - 1994 | NO | NO | NO | NO | NO | NO |
| 1965 - 1995 | NO | NO | NO | NO | NO | NO |
| 1966 - 1996 | NO | NO | NO | NO | NO | NO |
| 1967 - 1997 | NO | NO | NO | NO | NO | NO |
| 1968 - 1998 | NO | NO | NO | NO | NO | NO |
| 1969 - 1999 | NO | NO | NO | NO | NO | NO |
| 1970 - 2000 | NO | NO | NO | NO | NO | NO |
| 1971 - 2001 | NO | NO | NO | NO | NO | NO |
| 1972 - 2002 | NO | NO | NO | NO | NO | NO |
| 1973 - 2003 | NO | NO | NO | NO | NO | NO |
| 1974 - 2004 | NO | NO | NO | NO | NO | NO |

support the convergence hypothesis in both cases, especially in the case of the average of OECD15. As we can see from Table 5, only Denmark and Sweden exhibit some convergence with the United States. We are able to reject the hypothesis of no convergence both for Denmark and Sweden for the first three contiguous 30-year sub-sample periods. Nevertheless, for all the next 30-year sub-sample periods, we can not find evidence that support convergence with the United States. Moreover, we find some evidence of convergence with the United States, though much less evident, for Norway and Australia. In fact, we can reject at the 10% significance level the hypothesis of no convergence between Norway and the United States for three out of five 30-year periods covering 2000 back to 1996. Much the same can be said for Australia, as we can reject the no convergence hypothesis between Australia and the United States for three out of five 30-year periods ending from 1998 until 2002. Further, in the case we select the average of OECD15 as benchmark, we find overwhelming evidence against the convergence between the OECD15 countries and the average of this group. Despite the finding of two contiguous sub-sample periods that support convergence between Denmark and the average of

**Table 5**

Rolling Regression Test of real per capita GDP between the United States and OECD15 countries

| | AUS | AUT | BEL | CAN | DNK | FIN | FRA | ITA | JPN | NLD | NOR | SWE | CHE | GBR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1950 - 1980 | NO | NO | NO | NO | YES | NO | NO | NO | NO | NO | NO | YES | YES | NO |
| 1951 - 1981 | NO | NO | NO | NO | YES | NO | NO | NO | NO | NO | NO | YES | NO | NO |
| 1952 - 1982 | NO | NO | NO | NO | YES | NO | NO | NO | NO | NO | NO | YES | NO | YES |
| 1953 - 1983 | NO | NO | NO | NO | NO | NO | NO | NO | NO | YES | NO | NO | NO | NO |
| 1954 - 1984 | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| 1955 - 1985 | YES | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | YES |
| 1956 - 1986 | NO | NO | NO | NO | YES | NO | NO | YES | NO | NO | NO | NO | NO | NO |
| 1957 - 1987 | NO | NO | NO | NO | NO | NO | NO | YES | NO | NO | NO | NO | NO | YES |
| 1958 - 1988 | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| 1959 - 1989 | YES | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| 1960 - 1990 | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| 1961 - 1991 | YES | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| 1962 - 1992 | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| 1963 - 1993 | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| 1964 - 1994 | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| 1965 - 1995 | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| 1966 - 1996 | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | YES | NO | NO | NO |
| 1967 - 1997 | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| 1968 - 1998 | YES | NO | NO | NO | NO | NO | NO | NO | NO | NO | YES | NO | NO | NO |
| 1969 - 1999 | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | YES |
| 1970 - 2000 | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | YES | NO | NO | NO |
| 1971 - 2001 | YES | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | YES |
| 1972 - 2002 | YES | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | YES |
| 1973 - 2003 | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | YES |
| 1974 - 2004 | NO | NO | NO | NO | NO | NO | YES | NO | NO | NO | NO | NO | NO | YES |

OECD15 at the beginning of the sample period, a larger number of contiguous 30-year sub-samples is needed to support the convergence hypothesis.

The next two tables concern with OECD25. In particular, Table 7 shows the significance test for output convergence between the United States series and those of the rest countries of OECD25, while Table 8 reports the same information with the average of OECD 25 as benchmark. Since, we have already reported the results for OECD15, we focus on the ten countries that we add to OECD15. In the case that we select the United States as benchmark, we can not find evidence for convergence between the United States and all these ten countries, but Luxembourg and New Zealand. As we can see from Table 7, there is clear convergence between Luxembourg and the United States for the 30-year periods ending from 1984 until the early 1990s. However, the most notable result is the finding of convergence between New Zealand and the United States, as we can reject the no convergence hypothesis for six out of nine 30-year periods ending from 1984 until 2002. Nevertheless, in the case that we select the average of OECD25, we find overwhelming evidence against convergence between the ten countries that we add to form OECD25 and the average of this group.

**Table 6**
Rolling Regression Test of real per capita GDP between OECD15 countries and the average of OECD15

| | AUS | AUT | BEL | CAN | DNK | FIN | FRA | ITA | JPN | NLD | NOR | SWE | CHE | GBR | USA |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1950 - 1980 | NO | YES | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| 1951 - 1981 | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| 1952 - 1982 | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| 1953 - 1983 | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| 1954 - 1984 | NO | NO | NO | NO | YES | YES | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| 1955 - 1985 | NO | NO | NO | NO | YES | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| 1956 - 1986 | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| 1957 - 1987 | NO | NO | NO | NO | NO | NO | YES | NO | NO | NO | NO | NO | NO | NO | NO |
| 1958 - 1988 | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| 1959 - 1989 | NO | NO | NO | NO | NO | YES | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| 1960 - 1990 | NO | NO | NO | NO | NO | NO | NO | NO | YES | NO | NO | NO | NO | NO | NO |
| 1961 - 1991 | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| 1962 - 1992 | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| 1963 - 1993 | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| 1964 - 1994 | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| 1965 - 1995 | NO | NO | YES | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| 1966 - 1996 | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| 1967 - 1997 | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| 1968 - 1998 | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| 1969 - 1999 | NO | NO | YES | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| 1970 - 2000 | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| 1971 - 2001 | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| 1972 - 2002 | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| 1973 - 2003 | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| 1974 - 2004 | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |

The last two tables deal with EU14. In fact, Table 9 provides the significance tests for real per capita GDP convergence between the EU countries and France, which may serve as a more stable indicator of EU policies and performance, while Table 10 reports the same information with the average of EU14 as benchmark. Overall, convergence is more evident between France and the United Kingdom. Almost half of the 30-year sample periods show evidence of convergence. Moreover, there is a sustained period for which convergence is evident, as we can reject the no convergence hypothesis for four out of five or alternatively five out of eight 30-year sample periods ending from 1991 until the late 1990s. Further, there are 30-year sample periods that support convergence for these two countries at the beginning of the sample period as well as in the last two sub-samples. In addition, there is also evidence for convergence between France and Ireland as well as France and Denmark for almost the last four contiguous 30-year sub-sample periods. On the contrary, we find awesome evidence against the convergence hypothesis, if we select the average of EU14 as benchmark. That is much the same result for the cases that we select the average of the group as the benchmark. Despite that the fact that there is two contiguous 30-year sample periods for Denmark and Finland that support the convergence with the average of EU14, a

**Table 7**

Rolling Regression Test of real per capita GDP between the United States and OECD25 countries

| | AUS | AUT | BEL | CAN | DNK | FIN | FRA | GRC | ISL | IRL | ITA | JPN | KOR | LUX | MEX | NLD | NZL | NOR | PRT | ESP | SWE | CHE | TUR | GBR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1953 - 1983 | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | YES | YES | NO | NO | NO | NO | NO | NO | NO |
| 1954 - 1984 | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | YES | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| 1955 - 1985 | YES | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | YES | NO | NO | NO | NO | NO | NO | NO | NO | NO | YES |
| 1956 - 1986 | NO | NO | NO | NO | YES | NO | NO | NO | NO | NO | YES | NO | NO | YES | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| 1957 - 1987 | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | YES | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | YES |
| 1958 - 1988 | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | YES | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| 1959 - 1989 | YES | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | YES | NO | NO | YES | NO | NO | NO | NO | NO | NO | NO |
| 1960 - 1990 | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | YES | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| 1961 - 1991 | YES | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | YES | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| 1962 - 1992 | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| 1963 - 1993 | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| 1964 - 1994 | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | YES | NO | NO | NO | NO | NO | NO | NO |
| 1965 - 1995 | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| 1966 - 1996 | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | YES | NO | NO | NO | NO | NO | NO |
| 1967 - 1997 | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | YES | NO | NO | NO | NO | NO | NO | NO |
| 1968 - 1998 | YES | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | YES | YES | NO | NO | NO | NO | NO | NO |
| 1969 - 1999 | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | YES | NO | NO | NO | NO | NO | NO | YES |
| 1970 - 2000 | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | YES | NO | NO | NO | YES | YES | NO | NO | NO | NO | NO | NO |
| 1971 - 2001 | YES | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | YES |
| 1972 - 2002 | YES | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | YES | NO | NO | NO | NO | NO | NO | YES |
| 1973 - 2003 | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | YES |
| 1974 - 2004 | NO | NO | NO | NO | NO | NO | YES | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | YES |

larger number of contiguous 30-year sample periods is need to support convergence.

Ultimately, it is evident that the benefits of modern technology are spreading across national borders and influencing economic performance. Of course, this diffusion occurs more quickly in some cases and for some countries than it does for others. Thus, while there are good reasons to expect some convergence in economic performance, especially with the growth of regional economic units, there are also reasons to expect that the paths of transition in economic performance may be different across nations. Indeed, in the process of observing nations over time, we can observe different forms of transitional behavior. Some groups of countries or economic regions behave in a similar way over time and appear to moving on a path towards some steady state growth pattern. Others appear to diverge over certain periods of time, fall behind and then turn around and show evidence of catching up.

Despite the fact that common technological progress seems to have been diffusing reasonably widely across economies, we find precious little evidence of convergence by applying the rolling

**Table 8**
Rolling Regression Test of real per capita GDP between OECD25 countries and the average of OECD25

| | AUS | AUT | BEL | CAN | DNK | FIN | FRA | GRC | ISL | IRL | ITA | JPN | KOR | LUX | MEX | NLD | NZL | NOR | PRT | ESP | SWE | CHE | TUR | GBR | USA |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1953 - 1983 | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| 1954 - 1984 | NO | NO | NO | NO | NO | YES | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| 1955 - 1985 | NO | NO | NO | NO | YES | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| 1956 - 1986 | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | YES | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| 1957 - 1987 | NO | NO | NO | NO | NO | NO | YES | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| 1958 - 1988 | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | YES | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| 1959 - 1989 | NO | NO | NO | NO | NO | YES | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| 1960 - 1990 | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | YES | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| 1961 - 1991 | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| 1962 - 1992 | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| 1963 - 1993 | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | YES | NO | NO |
| 1964 - 1994 | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| 1965 - 1995 | NO | NO | YES | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| 1966 - 1996 | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | YES | NO | NO | NO | NO | NO |
| 1967 - 1997 | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| 1968 - 1998 | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| 1969 - 1999 | NO | NO | YES | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | YES | NO | NO |
| 1970 - 2000 | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| 1971 - 2001 | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| 1972 - 2002 | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| 1973 - 2003 | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| 1974 - 2004 | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |

regression test. The failure to find considerable evidence to support convergence can be attributed to the transition dynamics. In other words, the vast majority of 30-year sample periods, that we study, contain series that have not achieved a steady state, but rather are in transition to some steady-state. In addition, a key weakness of the test is that the rolling regression is subject to the pitfalls that surround the use of output gaps measured relative to a particular benchmark. It is expected to find little evidence of convergence, selecting as benchmark the United States and apparently the results of every group would be possibly quite different if we select different benchmarks.

**Table 9**

Rolling Regression Test of real per capita GDP between France and EU14 countries

| | BEL | ITA | NLD | LUX | DNK | IRL | GBR | GRC | ESP | POR | AUT | FIN | SWE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1951 - 1981 | NO | NO | NO | NO | NO | NO | YES | NO | NO | NO | NO | NO | NO |
| 1952 - 1982 | NO | NO | YES | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| 1953 - 1983 | NO | NO | NO | NO | NO | NO | YES | NO | NO | NO | NO | NO | NO |
| 1954 - 1984 | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| 1955 - 1985 | NO | NO | YES | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| 1956 - 1986 | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| 1957 - 1987 | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| 1958 - 1988 | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| 1959 - 1989 | NO | NO | NO | NO | NO | NO | NO | YES | NO | NO | NO | NO | NO |
| 1960 - 1990 | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| 1961 - 1991 | NO | NO | NO | NO | NO | NO | YES | NO | NO | NO | NO | NO | NO |
| 1962 - 1992 | NO | NO | NO | NO | NO | NO | YES | NO | NO | NO | NO | NO | NO |
| 1963 - 1993 | YES | NO | NO | NO | NO | NO | YES | NO | NO | NO | NO | NO | NO |
| 1964 - 1994 | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| 1965 - 1995 | NO | NO | NO | NO | NO | NO | YES | NO | NO | NO | NO | NO | NO |
| 1966 - 1996 | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| 1967 - 1997 | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| 1968 - 1998 | YES | NO | NO | NO | YES | NO | YES | NO | YES | NO | NO | NO | NO |
| 1969 - 1999 | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| 1970 - 2000 | NO | NO | NO | NO | NO | YES | NO | NO | NO | NO | NO | NO | NO |
| 1971 - 2001 | NO | NO | NO | NO | YES | YES | NO | YES | NO | NO | NO | NO | NO |
| 1972 - 2002 | NO | NO | NO | NO | NO | YES | NO | NO | NO | NO | NO | NO | NO |
| 1973 - 2003 | NO | NO | NO | NO | YES | NO | YES | NO | NO | NO | NO | NO | NO |
| 1974 - 2004 | NO | NO | NO | NO | YES | YES | YES | NO | NO | NO | NO | NO | NO |

**Table10**

Rolling Regression Test of real capita GDP between EU14 countries and the average of EU14

| | BEL | FRA | ITA | NLD | LUX | DNK | IRL | GBR | GRC | ESP | POR | AUT | FIN | SWE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1951 - 1981 | NO | NO | NO | NO | NO | NO | YES | NO | NO | NO | NO | NO | NO | NO |
| 1952 - 1982 | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| 1953 - 1983 | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | YES | NO |
| 1954 - 1984 | NO | NO | NO | NO | NO | YES | NO | NO | NO | NO | NO | NO | YES | NO |
| 1955 - 1985 | NO | NO | NO | NO | NO | YES | NO | NO | NO | NO | NO | NO | NO | NO |
| 1956 - 1986 | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| 1957 - 1987 | NO | YES | NO | NO | NO | NO | NO | NO | YES | NO | NO | NO | NO | NO |
| 1958 - 1988 | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| 1959 - 1989 | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | YES | NO |
| 1960 - 1990 | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| 1961 - 1991 | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| 1962 - 1992 | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| 1963 - 1993 | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| 1964 - 1994 | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| 1965 - 1995 | YES | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| 1966 - 1996 | NO | NO | NO | NO | NO | NO | NO | NO | NO | YES | NO | NO | NO | NO |
| 1967 - 1997 | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| 1968 - 1998 | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| 1969 - 1999 | YES | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| 1970 - 2000 | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| 1971 - 2001 | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| 1972 - 2002 | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| 1973 - 2003 | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| 1974 - 2004 | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |

## 14. CONCLUSIONS

Primary purpose of this study is to deal with convergence with respect to real per capita GDP. At first stage, we described some of the stylized facts on growth and the most well-known theoretical growth mode, namely the neoclassical model, by presenting its empirical implications. At second stage, we focus on two dominant convergence definitions and described a spectrum of empirical methods and findings related to studying patterns of cross-country growth. The range is extensive and it continues to grow as researchers understand more about the facts surrounding growth across countries. In fact, the growth literature has shown that the Solow model has substantial statistical power in explaining cross-country growth variation, sufficiently many problems exist with this work that the causal significance of the model is still far from clear.

Several forces could result in the convergence of per capita output across economies over time. To the extent that the less-advanced economies can employ the technology of more-advanced economies, convergence is expected. The neoclassical growth model implies conditional convergence by postulating diminishing returns to capital.

Moreover, we applied two applied tests. The focus of our empirical analysis has been on the unit-root and trending properties of log per capita output gaps across different countries in a global context, as well as in specific geographical regions. Using PWT data sets we have found little evidence of log per capita output convergence at a global level, although there seems to be some evidence of club convergence, so long as the concept of a “club” is loosely defined to mean countries with pair-wise output gaps that are stationary with a constant mean. This concept does not, of course, rule out the possibility of the club membership to change over time, which renders it more of historical interest rather than immediate relevance for policy analysis.

Economic convergence is desirable because inordinate income disparity between rich and poor economies is offensive to human dignity, and it also continues to fuel the international tension that has existed since the colonial era. In the presence of social capability, investment (in both physical and human capital) in laggard economies will result in growth rates higher than those in leader economies. Moreover, the experience of several economies (e.g., Singapore, Thailand, Chili etc.) show that release of entrepreneurial energy, latent in every nation, holds the key to growth. Although we may not know exactly how to bring about social capability and release the energy, the accumulated evidence since World War II, and particularly since the mid-1980s, points to the market as a potent force.

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