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Testing Convergence in Economic Growth for OECD Countries

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Testing Convergence in Economic Growth for OECD Countries

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ABSTRACT

In this paper we propose a new test procedure with more general steady state information to test the convergence hypothesis for a specific economy. We consider a model where demeaned per capita output of an economy is a function of time trend and then set the convergence hypothesis as negative average slope of that model. Applying the new procedure to 22 OECD countries we find strong evidence of convergence for 20 countries towards their average level. We also consider the per capita output of USA as a common steady state level for OECD countries. Then using the per capita output gap from USA we test the convergence hypothesis for an individual economy. This approach also shows strong evidence in favour of convergence towards the USA for most economies. France and Iceland do not converge towards the average level of OECD countries although they are converging towards USA. Australia and New Zealand are showing the opposite pattern as they are converging towards the average level but moving away from USA. This study also points out why using standard unit root tests with Bernard and Durlauf's (1995) definition of convergence is inappropriate.

1. INTRODUCTION

The phenomenon of convergence of economic growth is one of the most striking features of modern economics. In neoclassical growth models a country's per capita growth rate tends to be inversely related to its starting level of per capita income. In particular, if countries are similar with respect to structural parameters for preferences and technology, then poor countries tend to grow faster than rich countries. That is, it is a prediction of neoclassical economic growth theory that differences in per capita income across different economies will tend to decrease or disappear over time. This is broadly referred to as the convergence hypothesis. In testing this convergence hypothesis a number of empirical studies, for example Bernard and Durlauf (1991, 1995), Dowrick and Nguyen (1989), Lee et al (1998), Mankiw et al (1992) and Sala-i-Martin (1996) have mostly focussed attention on OECD countries.

Baumol (1986), Barro (1991), Mankiw et al (1992), and Sala-i-Martin (1996) have interpreted the findings of a negative correlation between initial income and growth rates of a group of countries as evidence in favour of convergence. All these studies conclude in favour of convergence for OECD countries. Recently Evans and Karras (1996) criticised the above approach and suggested an alternative test procedure for a group of economies which avoids highly implausible assumptions as well as accounting for time series variation in output. More recently with a panel data approach Lee et al (1998) conclude that there is growth convergence between OECD countries at a rate of about 2% - 4%. Using various measures of productivity Dowrick and Nguyen (1989) show that per capita GDP as well as productivity levels converge across OECD countries. On the other hand, Bernard and Durlauf (1991, 1995) generally rejected the convergence hypothesis for

OECD countries using standard univariate and multivariate time series techniques. In the context of time series, the convergence hypothesis is interpreted as implying that output differences are transitory.

Unfortunately all these existing procedures can not investigate the convergence of a specific economy. One can only look at whether a group of countries converge overall. From the above discussions it is also clear that for similar data sets the results of different approaches are contradictory. Some work is needed to try and reconcile these differences.

In this paper we propose an empirical methodology to investigate the convergence of an individual economy. Our analysis differs from the previous studies in several regards. In particular, we consider the demeaned per capita output and the per capita output gap from USA as a function of time. We employ different econometric techniques which seem appropriate for the analysis of long-run growth behaviour of per capita output. We are able to determine whether a specific economy is converging or not and estimate the rate of convergence for each country towards a common steady state level. Applying this procedure we find strong evidence of convergence for most OECD countries. We also test the convergence hypothesis by considering the average change in the per capita output gap from USA. The results of this test are similar to that of the previous test procedure.

The plan of rest of the paper is as follows. In section 2 we briefly discuss the convergence hypothesis. Section 3 describes the data set. Section 4 outlines the test procedures and empirical study. Section 5 reports the empirical results and some discussion. Conclusions are drawn in section 6.

2. CONVERGENCE HYPOTHESIS

The neoclassical growth model pioneered by Solow (1956) has generated a large theoretical and empirical literature on the convergence of economic growth. In the literature researchers define the convergence hypothesis in several ways. Sala-i-Martin (1996) provides an extensive analysis of the cross section regression on economic growth, where he defines β-convergence and σ-convergence. Sala-i-Martin stated that "there is absolute β-convergence if poor economies tend to grow faster than rich ones, and a group of economies are converging in the sense of σ if dispersion of their real per capita GDP levels tends to decrease over time" (Sala-i-Martin, 1996, p1020).

Let y_{it} be the logarithm of per capita output for economy i ($i = 1, 2, \ldots, N$) during period t, and $g_{i,t,T} \equiv \frac{(y_{i,T} - y_{i,t})}{T}$ be economy i's annual growth rate of GDP between t and T, and σ_t be the standard deviation of y_{it} across i at time t, then σ-convergence can be found when $\sigma_{t+T} < \sigma_t$, for $T > 0$. For empirical analysis Sala-i-Martin and some others have applied the ordinary least squares method to the following regression model

$$g_{i,0,T} = \alpha + \beta y_{i,0} + \varepsilon_{i,T}, \qquad i = 1, 2, \ldots, N \qquad (2.1)$$

and interpreted the regression results of negative β, that is, $\beta < 0$ as in favour of absolute β-convergence, and treating $\beta \geq 0$ as the no convergence null hypothesis. They also modified model (2.1) by including a set of control variables x_i and consider the regression model as follows:

$$g_{i,0,T} = \alpha + \beta y_{i,0} + \gamma x_i + \varepsilon_{i,T}. \qquad (2.2)$$

A negative β implies convergence holds conditionally on some set of exogenous factors when $\gamma \neq 0$, and absolute convergence occurs, when $\gamma = 0$ and $\beta < 0$. Therefore, the convergence hypothesis is interpreted as the negative correlation between initial per capita output levels and subsequent average growth rates of a group of economies. This approach to convergence is the most commonly applied in the literature. Several studies conclude in favour of convergence for OECD countries using the above approach.

However, some researchers have pointed out that short-run transitional dynamics and long-run steady-state behaviour are mixed up in cross-section regressions. Bernard and Durlauf (1995) proposed a new definition of convergence which relies on the notions of unit roots and cointegration in time series:

(a) Countries i and j converge if the long-term forecasts of output for both countries are equal at a fixed time t, that is,

$$\lim_{n \to \infty} E(y_{i,t+n} - y_{j,t+n} | I_t) = 0 \qquad (2.3)$$

where I_t denotes all information available at time t.

(b) Convergence in multivariate output : Countries $m = 1, 2, \ldots, N$ converge if the long-term forecasts of output for all countries are equal at a fixed time t, that is

$$\lim_{n \to \infty} E(y_{1,t+n} - y_{m,t+n} | I_t) = 0 \qquad \forall\, m \neq 1 \qquad (2.4)$$

The definition of convergence asks whether the long-run forecasts of output differences tend to zero as the forecasting horizon approaches to infinity. Bernard and Durlauf (1995) state that the above definition of convergence will be satisfied if $y_{1,t+n} - y_{m,t+n}$ is a mean zero stationary process. They also remark that to find convergence between countries i and j, their outputs must be cointegrated with cointegrating vector [1, -1].

It is important to point out an inconsistency in Bernard and Durlauf's (1995) link between their definition and the stationarity of output differences. We can see that certain non stationary $y_{1,t+n} - y_{m,t+n}$ processes can also meet their definition of convergence. For example, suppose $y_{1,t+n} - y_{m,t+n}$ is a non stationary process and represented by the following model

$$y_{1,t+n} - y_{m,t+n} = \frac{\theta}{t} + u_t \quad ,$$

where $E(u_t) = 0$, and u_t is a stationary process. As $t \to \infty$, then $\frac{\theta}{t} \to 0$, so $y_{1,t+n} - y_{m,t+n}$ is also converging as

$$\lim_{n \to \infty} E\left(y_{1,t+n} - y_{m,t+n}\right) = 0$$

where n is an arbitrary shift along the time horizon.

In order to test convergence and common trends Bernard and Durlauf (1995) employ multivariate techniques developed by Phillips and Ouliaris (1988) and Johansen (1988, 1991). The Phillips and Ouliaris (1988) procedure tests for the number of linearly independent stochastic trends by analysing the spectral density matrix at zero frequency. If all countries are converging in per capita output, then the rank of the zero-frequency spectral density matrix of first difference of output deviations from a benchmark country must be zero. Using Phillips and Ouliaris bound test, they could not reject the null of no convergence for the group of 15 OECD countries.

Johansen's (1988, 1991) technique tests for cointegration by estimating the rank of the cointegrating matrix. According to the definition of Bernard and Durlauf (1995) convergence would imply the existence of p-1 cointegrating vectors and hence a common stochastic trend for a p dimensional output series. The individual output series to converge there must be p-1 cointegrating vectors of the form (1, -1) or one common long-run trend. Both test statistics for rank (trace and maximum eigenvalue) reject convergence in the group of 15 OECD countries. We would argue that the inconsistency between definitions of convergence and stationarity explains this negative finding.

On the other hand, Evans and Karras (1996) defined convergence as follows:

Economies 1, 2, . . . , N are said to converge if and only if, every y_{it} is non-stationary but every $y_{it} - \bar{y}_t$ is stationary, that is,

$$\lim_{n \to \infty} E_t\left(y_{i,t+n} - \bar{y}_{t+n}\right) = \mu_i \tag{2.5}$$

where $\bar{y}_t \equiv \sum_{i=1}^{N} y_{it} / N$, and convergence is absolute or conditional depending on whether $\mu_i = 0$ for all i or $\mu_i \neq 0$ for some i. The economies are said to diverge if, and only if, $y_{it} - \bar{y}_t$ is non-stationary for all i.

As with Bernard and Durlauf's definition, we point out that equation (2.5) is not equivalent to a definition of stationarity. It can be easily shown that a non stationary $y_{it} - \bar{y}_t$ process can also meet the above definition of convergence. For example, let $y_{it} - \bar{y}_t$ be represented by the following model

$$y_{it} - \bar{y}_t = \frac{\theta}{t} + u_{it} ,$$

where $E\left(u_{it}\right) = 0$, and u_{it} is stationary. Then the non stationary process $y_{it} - \bar{y}_t$ is also converging as $\lim_{n \to \infty} E\left(y_{i,t+n} - \bar{y}_{t+n}\right) = 0$. Therefore, stationarity is not a necessary condition for the existence of convergence as defined in equation (2.5).

With the above definition Evans and Karras introduced a panel data approach to test whether convergence is conditional or absolute for a group of countries. In their empirical analysis, Evans and Karras [1996] used the following model to determine the convergence of a group of economies

$$\Delta(y_{it} - \bar{y}_t) = \delta_i + \rho_i(y_{i,t-1} - \bar{y}_{t-1}) + \sum_{n=1}^{p} \varphi_{in}\Delta(y_{i,t-n} - \bar{y}_{t-n}) + u_{it} \tag{2.6}$$

where ρ_i is negative if the economies converge and zero if they do not converge, δ_i is a parameter and φ's are parameters such that all roots of $\sum_n \varphi_{in} L^i$ lie outside the unit circle, where L^i represent the ith lag operator and u's are uncorrelated across economies.

Their procedure is two fold. At first they calculate the normalized series

$$\hat{Z}_{it} \equiv (y_{it} - \bar{y}_t) / \hat{\sigma}_i \qquad \text{for each } i,$$

where $\hat{\sigma}_i$ is the ordinary least square (OLS) estimate of standard error of the equation (2.6) for individual economy. Then obtained the parameter estimate $\hat{\rho}$ and its t-ratio $\tau(\hat{\rho})$ applying OLS to the normalized series

$$\Delta\hat{Z}_{it} = \bar{\delta}_i + \rho\hat{Z}_{i,t-1} + \sum_{n=1}^{p} \varphi_{in}\Delta\hat{Z}_{i,t-n} + \bar{u}_{it} \tag{2.7}$$

as a panel for $i = 1, 2, \ldots, N$ and $t = 1, 2, \ldots, T$, where $\bar{\delta}_i = \dfrac{\delta_i}{\hat{\sigma}_i}$ and $\bar{u}_{it} = \dfrac{u_{it}}{\hat{\sigma}_i}$.

Under the null hypothesis $H_0: \rho = 0$, $\tau(\hat{\rho})$ converges in distribution to standard normal as T and N approach infinity while N/T approaches zero. If the null hypothesis H_0: $\rho = 0$ can be rejected in favour of the convergence hypothesis H_1: $\rho < 0$, then the next step would be to test whether convergence is absolute or conditional. This test can be done by calculating the F-ratio as follows

$$\phi(\hat{\delta}) = \frac{1}{N-1}\sum_{i=1}^{N}\left[\tau(\hat{\delta}_i)\right]^2, \tag{2.8}$$

where $\tau\left(\hat{\delta}_i\right)$ is the t-ratio of the OLS estimator of δ_i from equation (2.6) for economy i and F-ratio $\phi\left(\hat{\delta}\right)$ converges in distribution to F[N-1, $(N$-1)(T - p -2)], as T approaches infinity while N and p remain fixed, where p is the number of lags. To make a conclusion of conditional convergence one should reject the null hypothesis of absolute convergence.

Applying the above procedure Evans and Karras (1996) found strong evidence in favour of conditional convergence for the 48 contiguous US states and a group of 54 countries. For inference they employ Monte Carlo simulations to provide approximate distributions for their samples.

All the studies reported here analyse the convergence hypothesis for a group of economies. The main objective of this study is to investigate the convergence of an individual economy using time series approach. We also rework the techniques to allow for nonstationary but converging output differences. In section 4 we will establish the definition of absolute convergence and the convergence hypothesis for an individual economy.

3. DATA

We have used the data for annual per capita GDP for twenty two OECD countries from 1950 to 1990. This data set was downloaded from the Penn World Tables 5.6 of Summers and Heston (1991) as updated in 1993. We are interested in this sample because the convergence hypothesis has been rejected in a time series technique by Bernard and Durlauf (1995) for 15 OECD countries out of these 22 OECD countries. The natural logs of the 22 OECD countries real per capita GDP series are plotted in Figure 1, where the data seem to show clear evidence of convergence. The plot of the standard deviation of real per capita GDP against time for these 22 OECD countries is given in Figure 2, which indicates evidence in favour of σ-convergence as defined by Sala-i-Martin (1996). Figure 3 represents the demeaned per capita GDP and all of these per capita GDP deviations seem to be heading towards zero, which is also an evidence of convergence.

4. TEST PROCEDURE AND EMPIRICAL STUDY

Let y_{it} be the logarithm of per capita output for economy i (i = 1, 2, . . . , N) during period t. Assume that these economies have eventual access to the common body of technical knowledge. Let a_t be the common trend followed by these economies and μ_i be a country-specific parameter, then with the knowledge of non stochastic neoclassical growth models, for economy i, we have

$$\lim_{n\to\infty}\left(y_{i,t+n} - a_{t+n}\right) = \mu_i \quad . \tag{4.1}$$

In the above equation, let a_t be the common technology available to these economies and the parameter μ_i determines the level of economy i's parallel balanced growth path, where for all economies μ_i would be non zero, unless the economies have identical structures. The definition of convergence given by Evans and Karras (1996) in equation (2.5) is an extension of the above non-stochastic growth model to the stochastic world. From equation (2.5) the definition of absolute convergence is as follows

$$\lim_{n\to\infty} E_t\left(y_{i,t+n} - \bar{y}_{t+n}\right) = 0 \quad , \tag{4.2}$$

which implies that the long run average of $y_{it} - \bar{y}_t$ must converge to zero, as the forecast horizon grows.

Let us define $z_{it} = y_{it} - \bar{y}_t$ as the demeaned per capita output, where $\bar{y}_t$ may be considered as the steady state information for all countries at time t. Since z_{it} represents the per capita output distance from their steady state value, z_{it} approaching to zero as time progresses should be considered as evidence of convergence. If z_{it} is heading towards zero with time then for every positive and negative z_{it}, the rate of change in z_{it} with respect to time t is negative and positive respectively. Or, if z_{it} is converging towards zero then for every z_{it}, the rate of change in $|z_{it}|$ with respect to time t is negative, ie, $\frac{\partial}{\partial t}|z_{it}| < 0$.

For simplicity let us consider $w_{it} = z_{it}^2$. For convergence to hold w_{it} should always be getting closer to zero; the rate of change in w_{it} with respect to time would be negative, ie, $\frac{\partial}{\partial t} w_{it} < 0$. The definition of absolute convergence in equation (4.2) implies that

$$\lim_{n \to \infty} E_t\left(w_{it+n}\right) = 0 \ , \tag{4.3}$$

where $w_{it} > 0$ and $\frac{\partial}{\partial t} w_{it} < 0$, is consistent with $w_{it+n} \to 0$ as $n \to \infty$.

Therefore, whether an economy is converging can be evaluated from the sign of $\frac{\partial}{\partial t} w_{it}$.

To find $\frac{\partial}{\partial t} w_{it}$, let us represent w_{it} as a function of time trend t, say $f(t)$, and consider

$$f(t) = \theta_0 + \theta_1 t + \theta_2 t^2 + ...+ \theta_{k-1} t^{k-1} + \theta_k t^k \tag{4.4}$$

where θ_i's are parameters. From (4.4) we can easily find

$$\frac{\partial}{\partial t} w_{it} = f'(t) \tag{4.5}$$

which is the slope function. One can use this slope function to check the convergence of an economy.

In reality the w_{it} series may not have a tendency to decrease uniformly with time. But if the economy tends to converge then w_{it} series should be generally decreasing. We consider whether the average of these slopes is negative. We say that for convergence to hold, the average slope function of w_{it} will be negative. That is,

$$\frac{1}{T}\sum_{t=1}^{T}\frac{\partial}{\partial t}w_{it} < 0.$$

This can be obtained from equation (4.5) as follows

$$\frac{1}{T}\sum_{t=1}^{T}\frac{\partial}{\partial t}w_{it} = \theta_1 + \theta_2 r_2 + \ldots + \theta_{k-1}r_{k-1} + \theta_k r_k = r'\theta$$

where $r_2 = \frac{2}{T}\sum_{t=1}^{T} t$, . . ., $r_{k-1} = \frac{(k-1)}{T}\sum_{t=1}^{T} t^{k-2}$, $r_k = \frac{k}{T}\sum_{t=1}^{T} t^{k-1}$,

$r = [0 \quad 1 \quad r_2 \quad . \quad . \quad . \quad r_{k-1} \quad r_k]$, and $\theta = [\theta_0 \quad \theta_1 \quad . \quad . \quad . \quad \theta_{k-1} \quad \theta_k]$. (4.6)

To test the convergence hypothesis let us define the following null hypothesis H_0 : $r'\theta \geq 0$, against the alternative hypothesis H_1 : $r'\theta < 0$. Thus we set our null hypothesis as no convergence. To test this let us consider the following model

$$w_{it} = f(t) + u_{it} = \theta_0 + \theta_1 t + \theta_2 t^2 + \ldots\ldots + \theta_{k-1}t^{k-1} + \theta_k t^k + u_{it} , \qquad (4.7)$$

where u_{it} are assumed to be an i.i.d $(0,\sigma^2)$ error term. Equation (4.7) can be written in matrix notation as

$$w = X\theta + u \qquad (4.8)$$

where $X = \begin{bmatrix} 1 & 1 & 1^2 & . & . & 1^k \\ 1 & 2 & 2^2 & . & . & 2^k \\ . & . & . & . & . & . \\ . & . & . & . & . & . \\ 1 & T & T^2 & . & . & T^k \end{bmatrix}$ $w = \begin{bmatrix} w_{i1} \\ w_{i2} \\ . \\ . \\ w_{iT} \end{bmatrix}$ $u = \begin{bmatrix} u_{i1} \\ u_{i2} \\ . \\ . \\ u_{iT} \end{bmatrix}$.

Using ordinary least square (OLS) we have $\hat{\theta} = (X'X)^{-1}X'w$, where $\hat{\theta}$ is the estimate of θ. Then the estimate of the average slope is $r'\hat{\theta} = r'(X'X)^{-1}X'w$, and the estimated standard error of $r'\hat{\theta}$ is $se(r'\hat{\theta}) = \sqrt{\left(r'\left[s^2(X'X)^{-1}\right]r\right)}$, where s^2 is the estimate of the error variance σ^2. To test the above null hypothesis the appropriate test statistic is

the t-ratio, $t_\theta = \dfrac{r'\hat{\theta}}{se\left(r'\hat{\theta}\right)}$. (4.9)

Under the null hypothesis the test statistic t-ratio follows an asymptotic normal distribution. The validity of the test is dependent on the regression in equation (4.7) being based on adequate assumptions such as normality. To check the normality assumption we use a Bera-Jarque test. After estimating our model (4.7) by OLS, denoting the residuals from the regression by e_{it} , the Bera-Jarque test statistic is then

$$\lambda = \mathrm{T}\left[\frac{(\sqrt{b_1})^2}{6} + \frac{(b_2-3)^2}{24}\right],$$

where $\sqrt{b_1} = (1/T)\sum_{t=1}^{T} \hat{e}_{it}^3 / \hat{\sigma}^3$ is an estimate of skewness coefficient, $\sqrt{\beta_1} = \mu_3 / \sigma^3$,

$b_2 = (1/T)\sum_{t=1}^{T} \hat{e}_{it}^4 / \hat{\sigma}^4$ is an estimate of scaled measure of kurtosis, $\beta_2 = \mu_4 / \sigma^4$,

$\hat{\sigma} = s = ((1/T)\sum_{t=1}^{T} \hat{e}_{it}^2)^{1/2}$ is an estimate of the standard error, σ , and $\mu = E(e_{it})$ the population mean of e_{it} . The test statistic λ is asymptotically distributed as a χ^2 random variable with 2 degrees of freedom under the null hypothesis that the e_{it} are normally distributed, against the alternative hypothesis that the e_{it} are not normally distributed. The results of these tests will be discussed in the next section.

From Figure 1 it seems that all other countries are heading towards USA, which is the richest country of this group. This can be interpreted as poor countries are growing faster than rich countries, which is defined as absolute convergence by Sala-i-Martin. Therefore, we can also check whether this data sets shows any evidence in favour of absolute convergence towards USA. Our main focus in this study is to test the convergence for an individual economy and thus we want to test whether or not every other OECD countries are converging towards USA.

Let us define $d_{it} = y_{it} - y_{ut}$ as the per capita output gap, where y_{ut} is the per capita output of USA, which may be considered as a targeted economy or a common steady state value of the OECD sample. Since d_{it}, the per capita output gap, measures the shortfall or distance from potential per capita output or steady state level for each country, d_{it} approaching zero as time progresses should be considered as evidence for convergence.

In order to find absolute convergence by checking the time series properties of d_{it}, we are considering a special case of the definition of convergence defined by Bernard and Durlauf (1995) as stated in equation (2.3). If in equation (2.3) country j is fixed as a targeted country u then the definition of convergence can be stated as:

Country i will converge towards a targeted country u if the long-term forecasts of output for both countries are equal at a fixed time t, that is,

$$\lim_{n \to \infty} E(y_{i,t+n} - y_{u,t+n} | I_t) = 0 .$$

Thus according to Bernard and Durlauf (1995) if we test the stationarity properties of each d_{it} we should find enough evidence to reject the unit root null hypothesis for most of these countries in favour of convergence. Figure 4 represents the graph of all these per capita output gap from USA for 21 OECD countries against time and shows evidence that most of these d_{it} are heading towards zero as time increases, which implies clear evidence of convergence towards USA for most of these countries. From this graph it is also clear that most of these d_{it} may not be stationary, throwing into doubt the usefulness of Bernard and Durlauf's test for convergence based on unit root test.

Following Bernard and Durlauf we use the Augmented Dickey-Fuller (1992) unit root test. We test the null of non-stationarity against stationarity (convergence). We also test the convergence hypothesis by calculating the slope of the output gap from USA for each economy and using the technique introduced earlier in this section. For our data set the per capita output of all countries are lower than their steady state level (US GDP), therefore, we only have negative d_{it}. For convergence to hold, the rate of change in d_{it} with respect to time t needs to be positive, ie, $\frac{\partial}{\partial t} d_{it} > 0$. We set our convergence hypothesis as that the average slope function is above zero.

To test the convergence hypothesis let us define the following null hypothesis $H_0 : r'\theta \leq 0$, against the alternative hypothesis $H_1 : r'\theta > 0$. To test this hypothesis we consider a similar model as equation (4.7):

$$d_{it} = f(t) + u_{it} = \theta_0 + \theta_1 t + \theta_2 t^2 + \ldots\ldots + \theta_{k-1} t^{k-1} + \theta_k t^k + u_{it} \, , \qquad (4.10)$$

where u_{it} is assumed to be an i.i.d (0, σ^2) error term, and use the same test statistics t-ratio as equation (4.9).

We can also test the convergence hypothesis in the following way. Let us define $l_{it} = d_{it} - d_{it-1}$ as the change in d_{it} for each time, l_{it} indicates whether the extent to which economy i is heading towards USA in period t. l_{it} should be positive in favour of convergence since d_{it} is always negative. In reality l_{it} may not be positive for each time period, but the average of l_{it} over time should be positive.

It can be easily tested whether l_{it} is positive on average for each country. Let us define the population average of l_{it} as μ_{il} and consider the following null hypothesis

$H_0 : \mu_{il} \leq 0$ against the alternative $H_1 : \mu_{il} > 0$. The alternative hypothesis represents the convergence hypothesis. To test this hypothesis the t-ratio can be used as follows:

$$t = \frac{\hat{\mu}_{il} - 0}{se(\hat{\mu}_{il})} \tag{4.11}$$

where $\hat{\mu}_{il}$ is an estimate of μ_{il} , $se(\hat{\mu}_{il}) = \sqrt{\frac{\hat{\sigma}^2}{T}}$ and $\hat{\sigma}^2$ is a consistent estimate of the variance of l_{it} and T is the number of useable observations. Under the null hypothesis this t-ratio follows an asymptotic normal distribution. The results of all these test will be reported in the next section.

5. RESULTS AND DISCUSSION

To test the convergence hypothesis at first we have to choose a particular form of $f(t)$ to estimate the model given in equation (4.7). We consider different forms of $f(t)$, which differ only by the maximum power of t. Then we estimate different models for each country. Using the Akaike (1973) information criterion (AIC) we select the appropriate model for each country. Table 1 represents the values of the AIC for various models of the squared demeaned output and the output gap from USA with different forms of $f(t)$. From Table 1 we select the models of the squared demeaned output and the output gap from USA, with polynomials of different degree for each country[1].

Table 2 represents the results of the test statistic t-ratio defined in equation (4.9). The second column of Table 2 reports the estimates of average slopes of squared

[1] Note: The results of the Bera-Jarque test for each selected model provide strong evidence in favour of the normality assumption of the error term for all selected models.

demeaned output, those within the brackets are estimated standard errors. Negative average slopes are observed for all countries except France and Iceland. The third column of the table shows the value of test statistics and within the parentheses the marginal significance levels, which indicate strong evidence in favour of the convergence hypothesis for each country except France and Iceland.

The fourth column of Table 2 reports the estimates of average slopes of the per capita output gap from USA, and within the brackets are estimated standard errors. Positive average slopes are observed for all countries except Australia and New Zealand. If the average slope of per capita output gap of a country is positive, this is evidence in favour of convergence towards the USA. The last column of the Table 2 shows the test statistics and marginal significance levels, which indicate strong evidence in favour of the convergence hypothesis for each country except Australia and New Zealand.

The estimates of average slopes-the average annual change in the per capita output gap can be interpreted as the average rate of convergence for each country towards USA. From the fourth column of Table 2 we can predict that Austria, Belgium, Canada, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Japan, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and UK are converging towards USA at the rate of 2.311%, 1.267%, 0.349%, 0.528%, 1.905%, 1.639%, 1.966%, 2.519%, 1.112%, 2.047%, 2.566%, 3.749%, 0.995%, 1.089%, 2.899%, 2.767%, 0.418%, 0.488%, and 0.553% per annum respectively. It is interesting to note that instead of converging New Zealand is diverging from USA at the rate of 0.76% respectively. The estimates of average slopes for Australia is also negative (-0.02%) but this is not significantly different from zero. Australia is not significantly diverging from USA, and it is not converging towards the USA.

Figures 5 and 6 represent the plots of squared demeaned per capita output and the fitted values of squared demeaned output for France and Iceland respectively. France was clearly diverging up till 1980, and some convergence has occurred after 1980. Iceland diverged 1967-1980, but was steady with the average rest of the time. So there is not strong evidence against convergence, except "temporary". Figures 7 and 8 represent the plots of the output gap and the fitted values for Australia and New Zealand respectively. Australia is converging very slowly towards USA on average, too slowly to be statistically significant. This explains why the non-convergence hypothesis cannot be rejected for Australia. New Zealand is diverging from USA most of the times, although it is converging before 1960. Clearly New Zealand is moving away from USA.

From the above discussion it is interesting to report that Australia and New Zealand are converging towards the cross-country average but they are not converging towards USA, although their rate of non-convergence/divergence is very slow on average. Similarly France and Iceland are not converging towards the cross-country average but they are converging towards USA. In Figure 9 we plot the per capita output of these 5 countries, together with the average of 22 OECD countries. From this graph it is clear that France is moving away from the average but is heading towards USA. Similarly Australia and New Zealand are heading towards the average but they are not heading towards the USA. As commented earlier, Iceland's movement away from the average is only temporary.

Table 3 represents the estimated average changes in per capita output gap, standard errors, the value of the test statistics defined in equation (4.11) and the p values of the test statistics. The results are similar to those from Table 2, for output gap from USA. The results of Table 3 also show that Australia's average rate of change in demeaned per capita output is not significantly positive and so it is not converging towards USA. This table also confirms that New Zealand is diverging from USA. So the result from Table 3 is consistent with Table 2.

Table 4 reports the results of Augmented Dickey-Fuller unit root tests for the output gap from USA, where lag length was chosen by AIC. Models include a constant but no time trend. Recall Bernard and Durlauf (1995) argue that rejection of the hypothesis of a unit root in output deviation implies convergence. From this table we can only reject the unit root null for Germany and Netherlands. Therefore, using unit root tests we can conclude in favour of convergence towards USA only for Germany and Netherlands. From this result it is clear that if we test for the convergence of this group of OECD countries by using a multivariate cointegration analysis, the convergence hypothesis defined as stationary output deviations, will be rejected. But according to our results and the graphical representations which we discuss above, most of these OECD countries are converging towards USA and also towards an average level, which can be considered as a common steady state level.

It is not surprising that the unit root test have thus given a misleading impression. The very slow convergence of most countries to the USA (Figure 4) is going to give an AR (1) coefficient in a Dickey-Fuller test very close to one, making it almost impossible to reject a null hypothesis of unity. Including a time trend in the unit root tests would possibly alleviate this, but then rejecting a unit root does not necessarily imply convergence. A significant trend in output gap would need to be positive. Even then, such a model with positive linear trend and stationary error is actually inconsistent with the definition of convergence, as long term forecasts of the output gap would not converge to zero. One could consider unit root test with deterministic functions of time which do yield converging long term forecasts (eg. $\frac{1}{t}$). Such models would be difficult to use as standard asymptotics on the unit root tests would not apply.

6. CONCLUSION

In this study an attempt has been made to answer empirically the question of whether there is convergence in output per capita for individual economies towards a common steady state level. We conclude in favour of convergence towards an average of OECD countries for Australia, Austria, Belgium, Canada, Denmark, Finland, Germany, Greece, Ireland, Italy, Japan, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland UK and USA. France and Iceland do not show enough evidence in favour of convergence towards the average. We reject the null hypothesis of no convergence for Austria, Belgium, Canada, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Japan, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and UK towards USA. All these countries are converging at different rates towards USA but only Australia and New Zealand not converging towards the USA. All graphical representations also show clear evidence in favour of convergence for most of these economies. Therefore, using both graphical and statistical analysis, it is straightforward to conclude that there is strong evidence for convergence in real per capita GDP for most of the OECD countries towards a common steady state level. This study supports one of the basic implications of neoclassical growth models. Our procedure can easily determine the convergence of a specific economy within a group of economies. From the results of Augmented Dickey-Fuller unit root tests it is also clear why Bernard and Durlauf reject the convergence hypothesis for many OECD countries, and why this approach is not suitable.

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TABLE 1

The Value of AIC for Different Models of squared demeaned per capita output and the per capita output gap from USA for 22 OECD Countries

Country		Model $w_{it} = f_k(t) + u_{it}$ and $d_{it} = f_k(t) + u_{it}$ where $f_k(t) = \theta_0 + \theta_1 t + \theta_2 t^2 + ... + \theta_k t^k$						
	$f_1(t)$	$f_2(t)$	$f_3(t)$	$f_4(t)$	$f_5(t)$	$f_6(t)$	$f_7(t)$	$f_8(t)$
Australia	-104.7	-158.5	-158.8	-156.9	-156.8	-154.9	-157.3	**-162.1**
	-128.4	-127.6	-129.8	-128.4	-127.1	-126.9	-132.7	**-134.0**
Austria	-137.8	-199.9	-231.4	-229.5	-234.6	-246.2	**-253.5**	-253.2
	-33.48	-116.9	-123.9	-121.9	-120.5	-142.4	**-143.7**	-141.8
Belgium	-233.7	-240.2	-280.2	-288.8	-322.6	**-324.3**	-322.6	-320.8
	-84.63	-96.98	-124.8	-123.3	-134.5	**-144.4**	-142.9	-140.9
Canada	-79.35	-153.3	-153.3	-154.6	-157.5	**-160.3**	-159.6	-157.7
	-133.9	-145.7	-148.5	-153.8	-162.5	-161.1	-177.5	**-178.0**
Denmark	-238.3	-243.6	-242.4	-243.0	-255.4	-270.9	-270.8	**-271.9**
	-83.28	-115.7	-114.0	-113.4	-130.9	**-131.9**	-130.3	-128.9
Finland	-246.0	-244.5	-245.9	**-253.3**	-251.5	-249.5	-247.6	-246.8
	-91.09	**-97.28**	-95.29	-97.20	-95.57	-96.15	-94.53	-92.96
France	-279.8	-310.6	-342.2	-341.1	-344.8	-348.1	**-350.2**	-348.6
	-64.81	-121.9	-143.3	-141.3	-142.20	**-156.7**	-154.9	-152.9
Germany	-255.1	-255.5	-284.2	-282.6	-283.6	-304.4	**-306.0**	-304.2
	-41.46	-110.7	-109.0	-127.4	-132.8	-148.4	**-151.4**	-149.4
Greece	-36.84	-61.4	-98.6	-115.7	-119.1	-118.9	-118.5	**-122.5**
	-28.08	-56.51	-114.8	-116.3	-130.3	-132.1	-134.9	**-135.7**
Iceland	-212.3	-220.3	-218.7	-229.3	-230.6	-236.4	-235.2	**-237.9**
	-68.73	-67.00	-65.00	-88.17	-86.72	-97.35	**-97.55**	-95.64
Ireland	-121.3	-144.7	-177.9	-176.0	-182.3	-184.7	-194.8	**-196.1**
	-81.35	-79.36	-105.2	-103.5	-110.6	-130.6	**-135.7**	-134.6
Italy	-171.4	-234.0	-282.3	-282.1	-280.1	-282.8	-281.3	**-291.5**
	-56.07	-113.3	-122.7	-123.0	-121.1	-129.0	**-129.1**	-128.4
Japan	-4.882	-79.81	-79.16	-98.94	-97.73	-111.8	-133.1	**-134.8**
	-37.48	-92.35	-113.6	**-126.1**	-124.8	-124.1	-125.4	-123.7
Netherlands	-174.7	-215.8	-214.1	-212.8	-215.5	-216.2	-223.3	**-229.5**
	-51.21	-115.5	-122.7	-120.7	-125.7	-140.3	-147.7	**-150.0**
New Zealand	-93.38	-134.3	-132.8	-131.1	-140.1	-153.9	**-157.2**	-155.3
	-77.74	-88.72	-87.31	-86.14	-89.65	-92.86	**-93.97**	-92.02
Norway	-222.6	-247.9	-246.2	-271.0	-277.3	**-287.5**	-285.6	-284.8
	-113.5	-112.2	-111.9	-148.4	-156.5	**-158.9**	-157.2	-155.2
Portugal	-45.64	-48.84	-48.81	-53.6	**-98.28**	-96.46	-96.18	-94.43
	-47.45	-62.13	-65.13	-67.82	-98.83	-101.2	**-101.5**	-99.48
Spain	-101.9	-146.9	-144.9	-151.2	-150.1	-154.4	-159.3	**-160.1**
	-23.52	-72.13	-82.90	-95.23	**-112.5**	-110.8	-108.9	-111.5
Sweden	-175.6	-230.2	-241.1	-239.3	-261.8	-261.6	-261.8	**-262.1**
	-114.9	-137.7	-136.4	-134.6	-137.3	**-138.2**	-136.7	-134.9
Switzerland	-149.3	-169.4	-182.0	-180.0	**-185.9**	-184.1	-182.7	-180.8
	-98.73	**-121.6**	-120.1	-118.1	-117.0	-116.7	-114.8	-113.1
U K	-178.3	-243.8	-311.5	-319.5	**-346.4**	-344.4	-343.0	-342.2
	-143.8	-158.8	-157.8	-160.2	-159.2	-163.8	-170.2	**-173.2**
USA	-61.92	-151.1	-149.3	-147.4	-145.7	-153.7	**-156.5**	-154.5

For the per capita output gap we have 21 countries. For each country 1st and 2nd rows represent the values of AIC for the models of the demeaned output and the output gap from USA respectively. The minimum value of AIC for each country is given in bold.

TABLE 2

Estimates of average slopes, standard errors, t -ratios, and p-values for testing convergence of 22 OECD countries

Country	Squared Demeaned Output		Output Gap	
	Average Slope [Standard Error]	Test Statistics (p value)	Average Slope [Standard Error]	Test Statistics (p value)
Australia	-0.01028 [0.0008]	-12.3837 (0.0000)	-0.00018 [0.0012]	-0.1564 (0.5616)
Austria	-0.00307 [0.0003]	-11.0043 (0.0000)	0.02211 [0.0011]	20.7816 (0.0000)
Belgium	-0.00079 [0.0001]	-8.7921 (0.0000)	0.01267 [0.0008]	15.8021 (0.0000)
Canada	-0.00788 [0.0007]	-11.9386 (0.0000)	0.00349 [0.0007]	5.1062 (0.0000)
Denmark	-0.00105 [0.0002]	-4.8065 (0.0000)	0.00528 [0.0009]	5.6569 (0.0000)
Finland	-0.00082 [0.0002]	-5.3944 (0.0000)	0.01906 [0.0006]	32.5746 (0.0000)
France	0.00038 [0.0001]	4.3911 (0.9999)	0.01639 [0.0007]	23.7437 (0.0000)
Germany	-0.00074 [0.0001]	-5.0320 (0.0000)	0.01966 [0.0010]	20.3109 (0.0000)
Greece	-0.01520 [0.0013]	-11.3045 (0.0000)	0.02519 [0.0011]	21.9939 (0.0000)
Iceland	0.00010 [0.0003]	0.2967 (0.6157)	0.01122 [0.0019]	6.0071 (0.0000)
Ireland	-0.00310 [0.0005]	-5.4672 (0.0000)	0.02047 [0.0012]	17.4545 (0.0000)
Italy	-0.00211 [0.0002]	-12.3241 (0.0000)	0.02566 [0.0013]	20.1730 (0.0000)
Japan	-0.03649 [0.0012]	-31.5230 (0.0000)	0.03749 [0.0007]	52.1971 (0.0000)
Netherlands	-0.00166 [0.0004]	-4.5616 (0.0000)	0.00995 [0.0010]	10.3450 (0.0000)
New Zealand	-0.01350 [0.0009]	-14.9629 (0.0000)	-0.00761 [0.0020]	-3.8981 (0.9998)
Norway	-0.00074 [0.0001]	-5.2940 (0.0000)	0.01090 [0.0007]	16.2305 (0.0000)
Portugal	-0.02532 [0.0014]	-17.5599 (0.0000)	0.02899 [0.0018]	16.2771 (0.0000)
Spain	-0.00807 [0.0009]	-9.4896 (0.0000)	0.02767 [0.0012]	22.8453 (0.0000)
Sweden	-0.00463 [0.0003]	-18.8894 (0.0000)	0.00418 [0.0009]	4.8419 (0.0000)
Switzerland	-0.0075 [0.0005]	-15.1607 (0.0000)	0.00488 [0.0004]	11.2288 (0.0000)
U K	-0.00236 [0.0001]	-33.7117 (0.0000)	0.00553 [0.0007]	7.6233 (0.0000)
USA	-0.01593 [0.0009]	-17.5031 (0.0000)		

TABLE 3

Estimates of average changes, standard errors, test statistic t-ratios, and p-values for testing convergence for 21 OECD Countries towards USA

Country				
	Average Change	Standard Error	Test Statistics	P value
Australia	0.00125	0.00089	1.39921	0.0848
Austria	0.02330	0.00087	26.7514	0.0000
Belgium	0.01202	0.00074	16.1775	0.0000
Canada	0.00433	0.00049	8.86173	0.0000
Denmark	0.00630	0.00088	7.16531	0.0000
Finland	0.01947	0.00106	18.4453	0.0000
France	0.01642	0.00069	23.7306	0.0000
Germany	0.02018	0.00075	26.8713	0.0000
Greece	0.02631	0.00099	26.5351	0.0000
Iceland	0.01180	0.00125	9.43221	0.0000
Ireland	0.01883	0.00077	24.5488	0.0000
Italy	0.02512	0.00081	31.2123	0.0000
Japan	0.03952	0.00084	47.0286	0.0000
Netherlands	0.01056	0.00083	12.6995	0.0000
New Zealand	-0.0052	0.00117	-4.4259	0.9999
Norway	0.01174	0.00070	16.6698	0.0000
Portugal	0.02876	0.00108	26.6351	0.0000
Spain	0.02701	0.00121	22.3767	0.0000
Sweden	0.00445	0.00075	5.91412	0.0000
Switzerland	0.00500	0.00081	6.17348	0.0000
U K	0.00614	0.00057	10.8233	0.0000

TABLE 4

Augmented Dickey-Fuller unit root test for the per capita output gap from USA

Countries	Lag Length	ADF Test Statistics	Conclusion
Australia	3	-1.58	Do not reject the null of unit root
Austria	0	-2.63	Do not reject the null
Belgium	0	-0.89	Do not reject the null
Canada	0	-0.67	Do not reject the null
Denmark	1	-2.24	Do not reject the null
Finland	0	-1.48	Do not reject the null
France	0	-2.17	Do not reject the null
Germany	0	-4.40	Reject the null
Greece	0	-1.58	Do not reject the null
Iceland	2	-2.05	Do not reject the null
Ireland	0	0.26	Do not reject the null
Italy	0	-2.52	Do not reject the null
Japan	0	-2.4	Do not reject the null
Netherlands	2	-3.69	Reject the null
New Zealand	1	-2.22	Do not reject the null
Norway	0	-1.34	Do not reject the null
Portugal	0	-0.77	Do not reject the null
Spain	0	-2.07	Do not reject the null
Sweden	0	-1.87	Do not reject the null
Switzerland	0	-2.10	Do not reject the null
UK	2	0.55	Do not reject the null

Lag length has chosen by AIC. Models include constant but not time trend. 5% critical value for the ADF test is -3.54.

Figure 1. Log of per capita GDP for 22 OECD countries

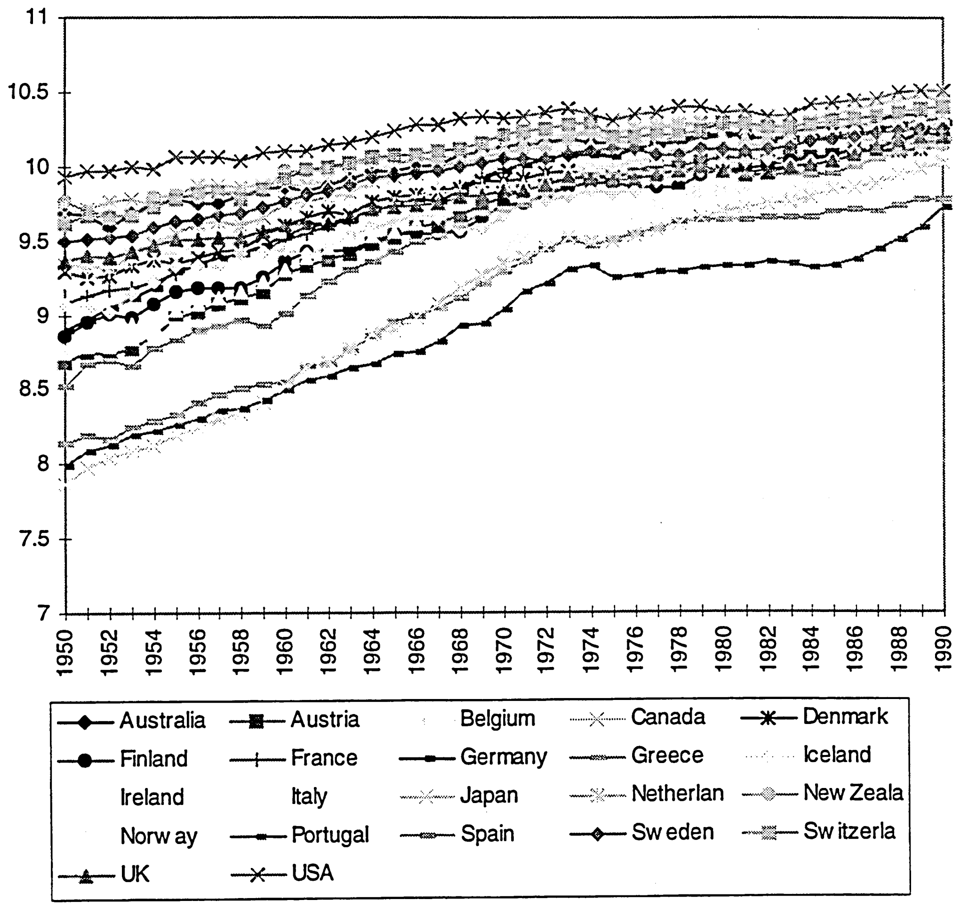


Figure 2. Standard deviation of log of real per capita GDP for 22 OECD countries

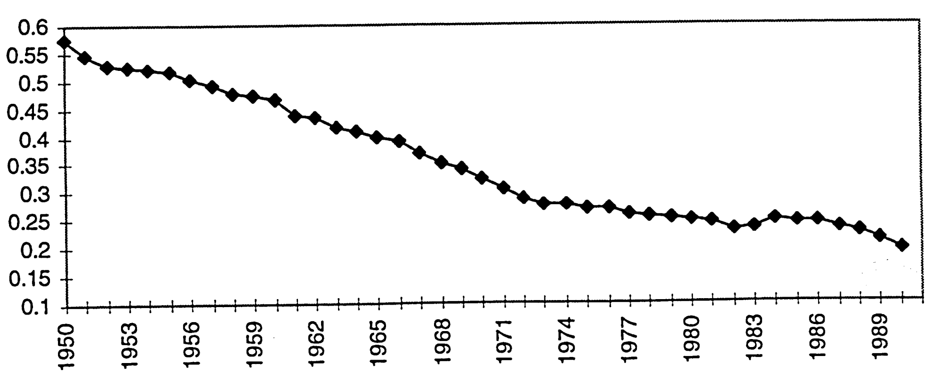


Figure 3. Demeaned per capita output for 22 OECD countries

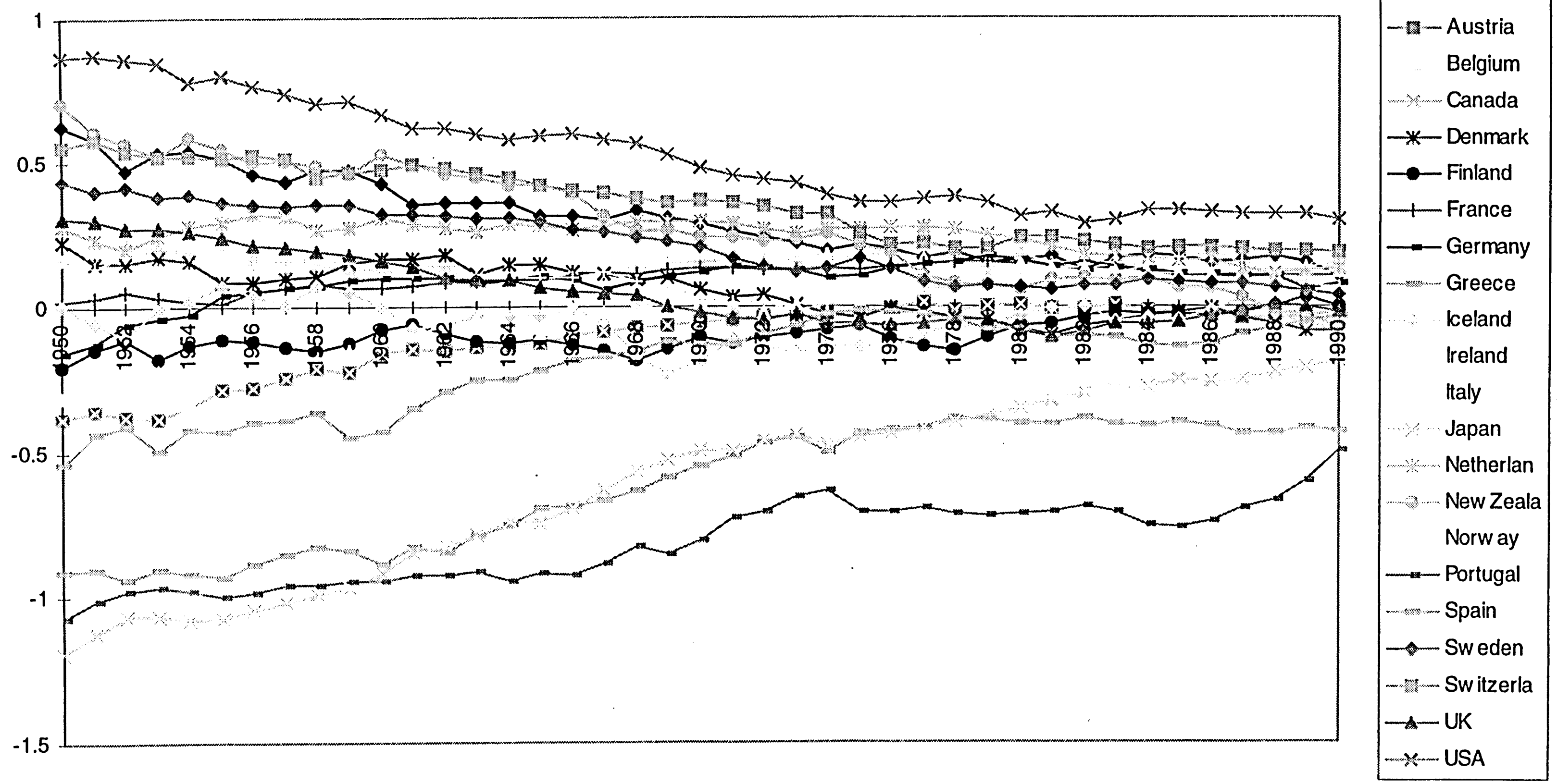
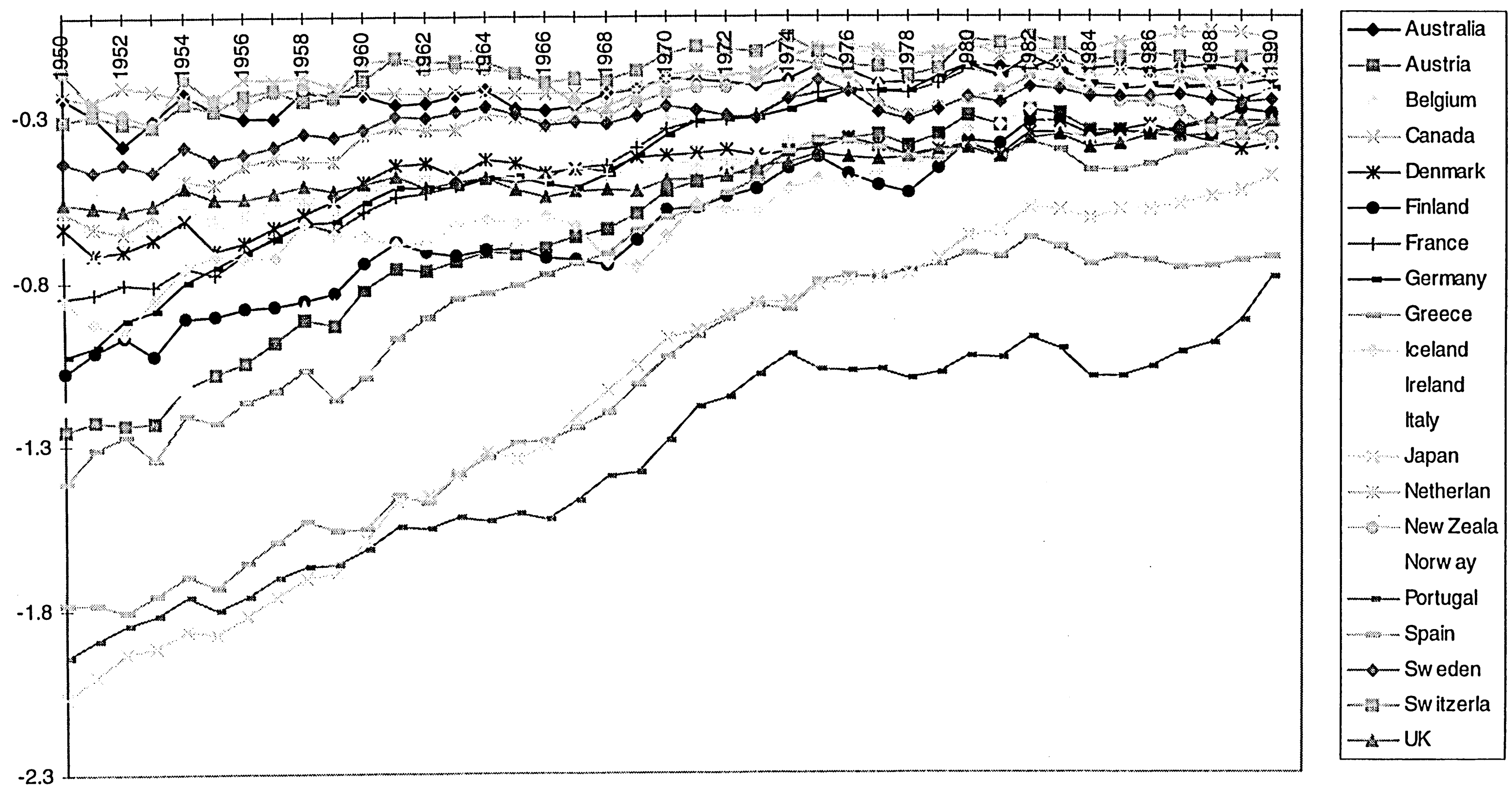


Figure 4. Per capita output gap from USA for 21 OECD countries



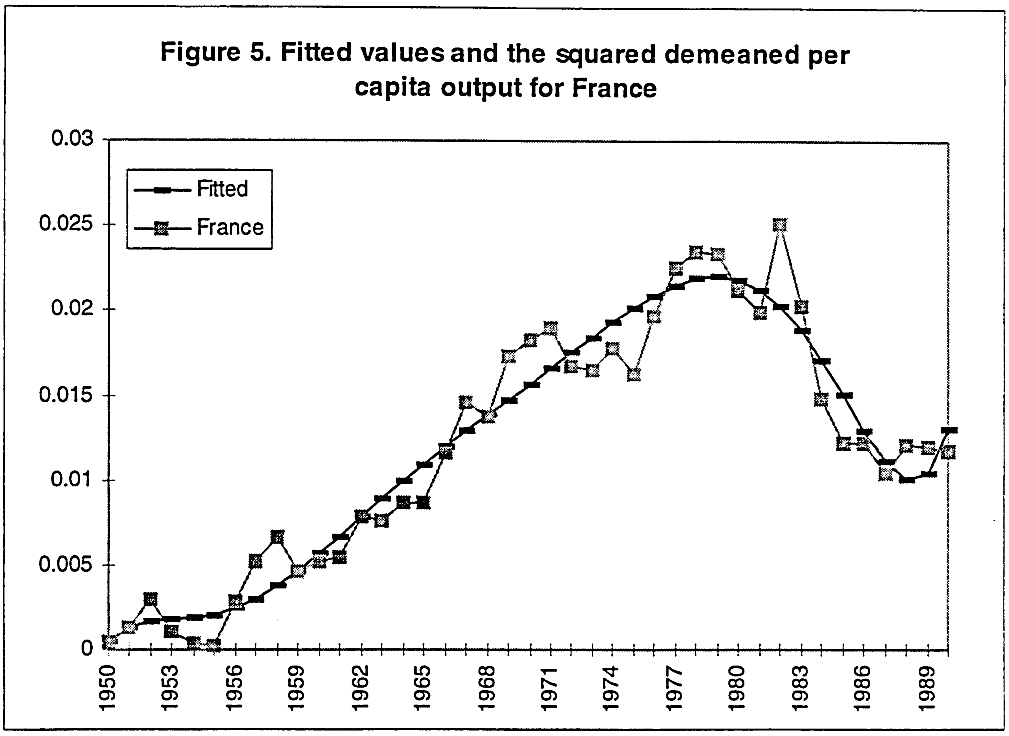


Figure 5. Fitted values and the squared demeaned per capita output for France
0.03
0.025
0.02
0.015
0.01
0.005
0
Fitted
France
1950
1953
1956
1959
1962
1965
1968
1971
1974
1977
1980
1983
1986
1989

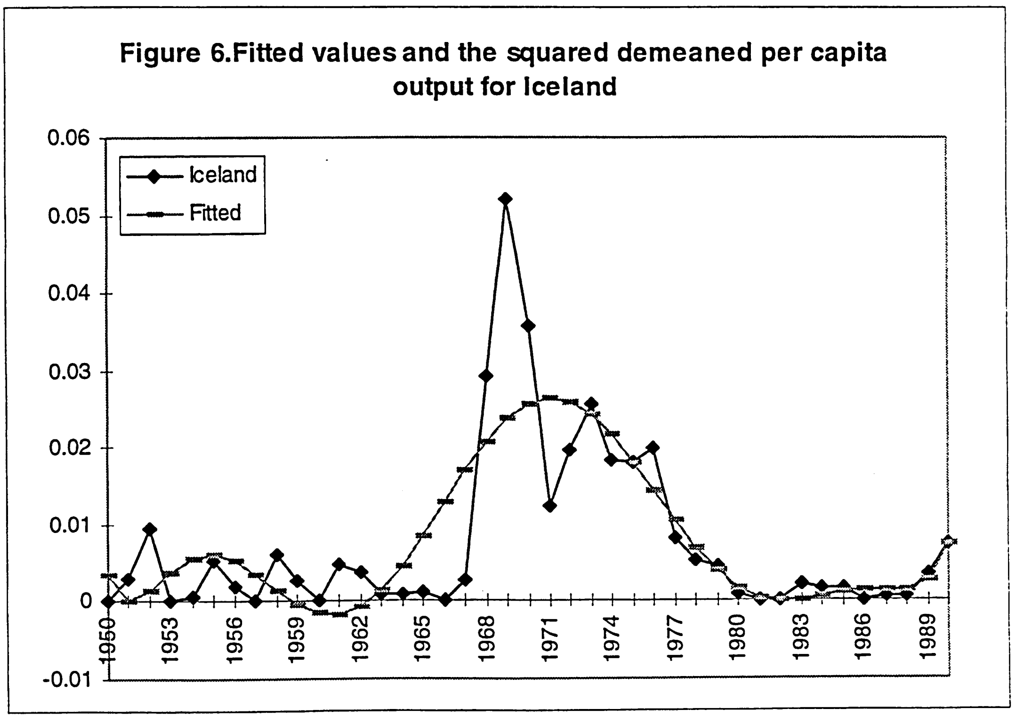


Figure 6.Fitted values and the squared demeaned per capita output for Iceland
0.06
0.05
0.04
0.03
0.02
0.01
0
-0.01
Iceland
Fitted
1950
1953
1956
1959
1962
1965
1968
1971
1974
1977
1980
1983
1986
1989

Figure 7. Fitted values and the per capita output gap from USA for Australia

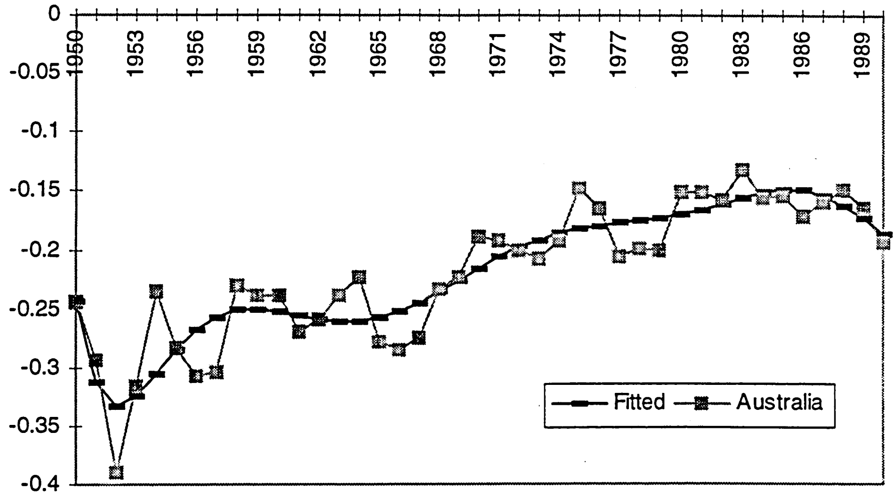


Figure 8. Fitted values and the per capita output gap from USA for New Zealand

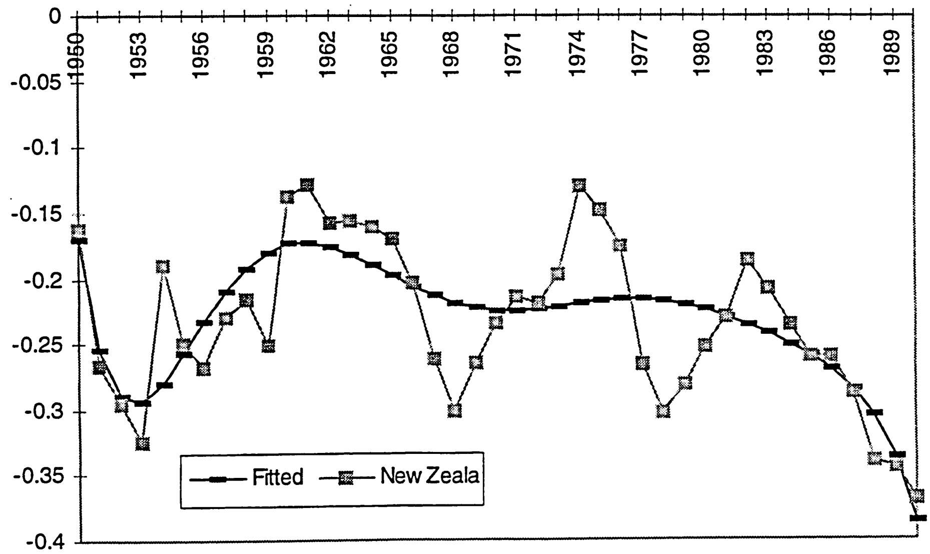


Figure 9. Log of per capita GDP for Australia, France, Iceland, New Zealand and USA with cross country average