Testing Convergence : A Panel Data Approach

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Abstract

This paper briefly presents new empirical tests of the convergence hypothesis based on panel data. We apply a modified Evans and Karras (1996) testing procedure to three samples (Europe, OECD and World).

We propose a nested tests procedure to characterize various convergence processes : absolute or conditional, with or without a common speed of convergence.

In the conditional convergence context, we are particularly concerned with the information included in individual effects.

We find evidence supporting the existence of an absolute and common convergence process for per capita GDP in the European Union sample (1960-1990). As concerns the OECD sample, structural disparities imply only a conditional convergence process occurring at country-specific speeds. For our World sample (86 countries) there is no convergence process at all.

For OECD countries, a first study of fixed effects is proposed. It shows that only the private and public investment ratios are significantly linked to those unobservable structural disparities.

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1 Introduction

For more than a decade, a large number of theoretical and empirical studies have investigated the origins of growth and convergence. The emergence of new econometric methods, the development of the new growth theories and the building of large data bases (Summers and Heston (1991), Maddison (1989)) have led economists to focus on the convergence debate. Following the pioneering work of Baumol (1986), considerable efforts have been devoted to investigate the pattern of convergence in different national and regional samples using two methodological approaches : the first one, based on cross-sectional data, proposes the two main concepts of β and σ convergence (Barro and Sala-i-Martin (1995)) whereas the second one, considering convergence as a stochastic process, uses the properties of time series (Bernard and Durlauf (1995)).

More recently, new testing procedures for the convergence hypothesis using panel data have been developed. These procedures bring together cross-sectional and time series analysis. Two main approaches have been proposed. A first group of studies have tried to extend the methodologies, designed for cross-sectional data, to the analysis of panel data (Knight, Loayza and Villanueva (1993), Islam (1995), Berthélemy, Dessus and Varoudakis (1996)). A second group used unit root testing procedures for panel data.

The recent progress realized in the extension of the unit root tests to the analysis of dynamic panel data models (Quah (1992), Quah (1994), Im, Pesaran and Shin (1995), Levin and Lin (1993) and Harris and Tzavalis (1996)) have allowed the development of testing procedures for the convergence hypothesis (Quah (1992), Bernard and Jones (1996) and Evans and Karras (1996)).

These different methodologies can be distinguished according to the models used for the test and the restrictions imposed under the unit root null hypothesis. If Quah (1992) neglects the heterogeneity of the data (his procedure does not include any fixed effects), on the contrary, Bernard and Jones (1996) take into account individual effects. However, the drawback of their approach is to assume a common first order autoregressive dynamics. This is not the case in Evans and Karras (1996) which impose *a priori* no restriction on parameters under the alternative hypothesis (AR coefficients are allowed to vary across economies). The advantage of this approach is to use a data generating process with an individual autoregressive dynamics.

In this paper, we propose a nested tests procedure, based on Evans and Karras (1996), which takes into account two sources of heterogeneity : individual effects and individual autoregressive dynamics. By testing for both sources of heterogeneity in a panel data set, we can characterize several convergence processes. A convergence process is assumed to occur when deviations of the per capita GDP from the international average approach individual constant values as time approaches infinity. If all these values are null, the convergence process is said absolute (convergence in levels). If at least one of these values is different from zero, the convergence process is said conditional (convergence in growth rates).

The procedure used by Evans and Karras tests for convergence and then characterizes it as absolute or conditional. But the alternative hypothesis of their test does not impose any restriction on the individual autoregressive structure. Thus, we perform two tests of the hypothesis of common speed of convergence.

Our study also proposes to go deeper into the treatment of the individual effects. Indeed, individual effects represent all the specific and the unobservable characteristics which affect the steady states of the different economies. These structural disparities are related to a set of variables including human capital, public and private investment.

Moreover, our paper extends the methodology of Evans and Karras (1996) into three directions : The number of lags included in the data generating process, so as to whiten residuals, will be country-specific; the robustness of our results will be then evaluated using critical values from different simulation procedures. Finally, we consider a larger sample than Evans and Karras, including many developing countries.

The remainder of the paper is organized as follows. The second section surveys the different approaches to test the convergence hypothesis using panel data. The third presents the approach of Evans and Karras (1996) and our modifications. Section 4 presents our results and the treatment of individual effects. In this section we also present the tests used to study the hypothesis of a common speed of convergence. Section 5 finally, briefly concludes.

2 The panel data tests of the convergence hypothesis

Empirical studies of the convergence hypothesis have recently benefited of the development of the unit root testing procedures. Indeed, a large number of studies have made possible the extension of these techniques to the analysis of panel data. Several procedures have been developed with different assumptions about the heterogeneity of the data generating process.

The unit root testing procedure proposed by Quah (1992) considers panel data where time and cross-section dimensions tend to infinity at the same speed. Conversely, Levin and Lin (1993) develop a test for panels with individual effects, where the asymptotic convergence of the two dimensions does not occur at the same rate. Im, Pesaran and Shin (1995) consider a test statistic, following Dickey-Fuller's test statistic whose average is computed over the N individuals. Furthermore, these authors focus on the case where N and T go to infinity and on the other case where T is fixed. This alternative is also taken into account by Harris and Tzavalis (1996) who develop unit root testing procedures for panel data based on the normalized bias of the Least Squares estimator.

These different unit root test provide relevant methods for testing the convergence hypothesis. Let us consider the stochastic definition of convergence given by Bernard and Durlauf (1995): *There is convergence between the log GDP per capita of country i, $y_{i,t}$, and the log GDP per capita of country j, $y_{j,t}$, if and only if their difference $y_{i,t} - y_{j,t}$ is stationary with zero mean.*

The test for this convergence hypothesis amounts to test whether the data generating process for $y_{i,t} - y_{j,t}$ contains a unit root.

The unit root tests proposed by Quah (1992, 1994) have the advantage of being easy to implement. Indeed let us consider the following model :

$$\hat{y}_{ij,t} = \beta \hat{y}_{ij,t-1} + \epsilon_{ij,t} \tag{1}$$

where $\hat{y}_{ij,t} = y_{i,t} - y_{j,t}$, $y_{i,t}$ is the logarithm of the GDP per capita for country i during the period t. Quah (1994) shows that under the unit root null hypothesis ($\beta = 1$) and as $T \to \infty$[1]

[1] In fact, using Monte-Carlo simulations, Quah shows that the statistic $t_{\hat{\beta}}$, converges in distribution to standard normal as well when T and N tend to infinity as when N is large but T is small.

$$t_{\hat{\beta}} \longrightarrow N(0,1)$$

But, the drawback of this method is to neglect fixed effects. In fact, the heterogeneity in the data is not taken into account by this approach which ignores also the problem of heteroskedasticity and different serial correlation structures.

The methodology of Bernard and Jones (1996) tries to compensate for this absence of individual effects. Following the results obtained by Levin and Lin (1993), Bernard and Jones (1996) propose a more complete data generating process than in Quah (1994). Indeed, let us consider a model without trend,

$$\hat{y}_{ij,t} = \mu_i + \beta \hat{y}_{ij,t-1} + \epsilon_{ij,t} \tag{2}$$

where $\epsilon_{ij,t} \longrightarrow N(0,\ \sigma_\epsilon^2)$ and where $\hat{y}_{ij,t}$ corresponds to the notations used in the equation (1).

Levin and Lin (1993) show that under the null hypothesis ($\beta = 1$) and under the hypothesis of no fixed effects ($\mu_i = 0, \forall i$), and as N and T tend to infinity while the ratio $\frac{\sqrt{N}}{T}$ goes to zero:

$$T\sqrt{N}\left(\hat{\beta} - \left(1 - \frac{3}{T}\right)\right) \quad \Longrightarrow \quad N(0, 10.2)$$

and

$$\sqrt{1.25 t_\beta} + \sqrt{1.875 N} \quad \Longrightarrow \quad N(0,1)$$

Nevertheless, the model proposed by Levin and Lin (1993)imposes the absence of individual effects under the null hypothesis of unit root. In order to overcome this limit, Bernard and Jones (1996) provide the following proposition:

Proposition 1 *: Assume that the model used is the one described by equation* 2 *under the null hypothesis* $\beta = 1$*, then as* N *and* T *approach infinity:*

$$\sqrt{N} T^{\frac{3}{2}} \left(\hat{\beta} - 1\right) \Longrightarrow N(0, 12 \frac{\sigma_\epsilon^2}{\sigma_\mu^2 + \bar{\mu}^2})$$

The small size samples issue is not ignored by Bernard and Jones (1996) who recognize that the least squares estimator $\hat{\beta}$ is unbiased under the null hypothesis only asymptotically. Moreover, the speed with which the asymptotic normality takes over is a function of the magnitude of the drift relative to the variance of the disturbance terms of the unit root process. These two sources of bias lead Bernard and Jones (1996) to correct the estimator of β by computing a correction term equal to the median bias obtained for the k simulations realized for the different critical values of $t_{\hat{\beta}}$[2].

Harris and Tzavalis (1996) propose unit root testing procedures based on different models. They provide the distribution of a test statistic under the null of non-stationarity, but this distribution depends on unobservable parameters. They propose a more complete model including some specific trends:

$$y_{i,t} = \mu_i + t\,\phi_i + \beta y_{i,t-1} + \epsilon_{i,t}$$

where $y_{i,t}$ is the logarithm of the GDP per capita for economy i at period t.

Under the null hypothesis, $\beta = 1$ and $\phi_i = 0$ $(\forall i)$, this model allows them to derive an expression of the bias as a function of the size of the sample. If the null hypothesis employed by Harris and Tzavalis (1996) is similar to the one used by Bernard and Jones (1996), their alternative hypothesis allows, on the contrary, for the presence of individual trends. But the presence of individual trends under the alternative hypothesis raises some questions about the validity of this method for testing the convergence hypothesis. Indeed, even if the null hypothesis of unit root can be rejected, the data generating process of the economies can be very different when $\phi_i \neq \phi_j, \forall i, j$. So, Harris and Tzavalis's approach may not be well adapted to the study of convergence[3].

If the approach of Bernard and Jones (1996) enables taking into account fixed effects under the null hypothesis as under the alternative one, it implies the equality of the parameters β for all individuals. This restriction is avoided by Evans and Karras (1996)[4]. These authors propose a more comprehensive procedure not only to test for the convergence hypothesis but also to characterize it (absolute or conditional convergence).

So, it appears that heterogeneity has firstly being introduced *via* fixed effects, and then *via* the autoregressive dynamic structures. Both sources of heterogeneity allow to consider more flexible convergence process.

[2] The adjusted estimate of β is equal to the estimate plus the bias correction term.

[3] We have to precise that Harris and Tzavalis (1996) present their test as a general unit root testing procedure using panel data and not as a specific test of the convergence hypothesis. However, they propose an application of their unit root tests to the problem of convergence.

[4] Im, Pesaran and Smith (1995) also consider heterogenous panels. They suggest in this case to use the mean group OLS estimator.

3 The modified Evans and Karras' (1996) approach

The methodological approach developed by Evans and Karras (1996) retains a quite general framework for testing the convergence hypothesis in panel data. It implies less restriction on the data generating process than alternative approaches. This section discusses this procedure and exposes some modifications we will apply in the last section.

Let us consider N countries. These economies ($i = 1, 2, ..., N$) converge if and only if the expected per capita GDP cross economies differences ($y_{it} - \overline{y}_t$) are stationary for all countries.

$$\lim_{p \to \infty} E_t \left(y_{it+p} - \overline{y}_{t+p} \right) = \mu_i \tag{3}$$

A convergence process occurs when deviations of the per capita GDP from the international average $\overline{y}_t$ approach individual constant values as time approaches infinity. Evans and Karras characterize the convergence process as absolute or conditional on the basis of individual effects μ_i :

- If $\mu_i = 0$, $\forall i = 1..N$, the convergence is said absolute since the per capita GDP converge in level to the international average.
- On the contrary, if some of these values are different from zero, the convergence process is said conditional. Per capita GDP converge to individual parallel long run paths : growth rates are common but level remain different.

To test the convergence hypothesis, Evans and Karras consider the following data generating process

$$\lambda_i(L)(y_{it-}\overline{y}_t) = \alpha_i + \epsilon_{it} \tag{4}$$

This process has two advantages. First, in contrast with cross section studies, all permanent cross economy differences are completely controlled for by the individual constants α_i. Indeed, given the great structural disparities between countries (technology gaps, permanent idiosyncratic shocks), we can not assume that control and environmental variables usually used in cross section analysis are likely to capture all impacts of such differences on individual dynamics. So, as in Bernard and Jones (1996), we get rid of the need to constitute an adequate conditioning variables space by using fixed effects which control for all unobservable timeless specificities.

Second, this approach is less restrictive than Bernard and Jones' (1996) one, as it allows economies to have different autoregressive dynamic structures. Particularly, the speed of convergence is not constrained to be identical across countries.

Evans and Karras use the following functional form of the general process (4) :

$$\Delta(y_{it} - \overline{y_t}) = \alpha_i + \rho_i(y_{it-1} - \overline{y}_{t-1}) + \sum_{j=1}^{p} \gamma_{i\,j}\Delta(y_{it-j} - \overline{y}_{t-j}) + \epsilon_{it} \qquad (5)$$

where all the parameters ρ_i are negative if the N economies converge and zero if they diverge, and where the roots of the polynomial $\sum_{j=1}^{p} \gamma_{ij} L^j$ are outside the unit circle. Parameters α_i denote individual effects without time dimension. Residuals ϵ_{it} are assumed to be asymptotically uncorrelated in the individual dimension.

Then, we face the problem of selecting the lag's length which eliminates residual autocorrelation. Its seems plausible that the lag order is not identical for all individuals. As Perron (1991) stresses, in the case of time series, the choice of the number of lags is crucial, because it affects both the level and the power of stationarity tests[5].

That is why, it appears better to test the lag length for each country. For that purpose, we will use the Hannan-Quin's criterion (1979)[6]. The power of the test is likely to be raised by this more parsimonious specification. Parameter estimation would be more robust than if we had uselessly kept a too large lag's order for some countries.

In practice, Hannan-Quin's criterium never selects more than two lags. But, our main concern is to well fit the dynamic structure of each country without imposing any constraint.

Consequently, we generalize equation (5) by the following :

$$\Delta(y_{it} - \overline{y}_t) = \alpha_i + \rho_i(y_{it-1} - \overline{y}_{t-1}) + \sum_{j=1}^{p_i} \gamma_{i\,j}\Delta(y_{it-j} - \overline{y}_{t-j}) + \epsilon_{it} \qquad (6)$$

The test procedure consists of four steps : the first three test convergence (stationary per capita GDP cross economies differences) versus divergence (nonstationary ones), the last step characterizes the convergence process as absolute or conditional.

First step : Model (6) is estimated by Ordinary Leasts Squares in order to collect for each country (each equation) the standard error of estimate $\widehat{\sigma}_i$. These N

[5] The first step of Evans and Karras (1996) procedure consists in N time series regressions.

[6] The Hannan-Quinn's criterion is : $Log(\widehat{\sigma}^2) + 2(p+q)Log(Log(T))/T$, where $\widehat{\sigma}^2$ is the residual variance, p the number of variables considered in the model, q the lag's order , T the sample size. The results are still the same when we use the Schwarz information criterion.

standard errors are used to generate normalized series $\widehat{z}_{it} = \frac{y_{it} - \overline{y}_t}{\widehat{\sigma}_i}$ $(i = 1..N)$. This normalization yields a model with a panel structure.

Second step : the normalized model is :

$$\Delta \widehat{z}_{it} = \delta_i + \rho \widehat{z}_{it-1} + \sum_{j=1}^{p_i} \gamma_{ij} \Delta \widehat{z}_{it-j} + \mu_{it} \tag{7}$$

where $\delta_i = \frac{\alpha_i}{\widehat{\sigma}_i}$. and $\mu_{it} = \frac{\epsilon_{it}}{\widehat{\sigma}_i}$. Evans and Karras show (pages 260-263) that the test $\rho_i = 0$ versus $\rho_i < 0$ in the model (6) is equivalent to the test $\rho < 0$, in the model (7) with a panel structure.

Then, in contrast to equation (6), the parameter ρ is common to all countries, nevertheless the parameters γ_{ij} associated with lagged differentiated terms remain individual specific. This model is estimated by Ordinary Least Squares with Dummy Variables (LSDV or fixed effects estimator).

Third step : we compare the t-statistic $t_{\widehat{\rho}}$ associated to $\widehat{\rho}$ to critical values obtained by simulation. If $t_{\widehat{\rho}}$ is greater than the critical value for a given level, we reject, for this level the null hypothesis $\rho = \rho_i = 0$ $(\forall i)$ in favor of the alternative hypothesis $\rho_i < 0$ $(\forall i)$.

If H_0 is rejected, we conclude to convergence without being able to characterize it as absolute or conditional. However, the rejection of H_0, consequently the acceptation of the convergence hypothesis, does not necessary mean that all economies converge. As it was discussed by Evans and Karras[7], it may be possible that some of the economies converge while the others diverge.

Fourth step : At this step, two kinds of convergence processes are possible. The first one is characterized by the convergence of individual per capita GDP level to the international average (absolute convergence). However, a more likely case is conditional convergence : growth rates converge but cross economies differences in level do not disappear in the long run.

Under the conditional convergence hypothesis, all the parameters α_i $(\forall i = 1..N)$ in equations (5) are different from zero. So, in order to test the null of absolute convergence, we compute the following F-statistic:

$$F_{\widehat{\delta}} = \frac{\sum_{i=1}^{N} t^2_{\widehat{\delta}_i}}{(N-1)} \tag{8}$$

We compare this statistic with a critical value obtained by simulation. If, for a given level, $F_{\widehat{\delta}}$ is greater than the simulated critical value, the null of absolute

[7] Page 252, note (4).

convergence is rejected in favor of the hypothesis of conditional convergence. Evans and Karras show[8] that, under H_0, $t_{\widehat{\rho}}$ et $F_{\widehat{\delta}}$ have standard distributions in the asymptotic case (as N and T approach infinity). But it is well-known that in finite samples asymptotic properties are misleading for several reasons.

The most obvious is the $Op(T)$ dynamic panel bias which affects the LSDV estimator (Nickell 1981). Given the time dimension of our samples ($T = 30$), our estimate of parameter ρ in equation (7) might be downward biased. Besides, distributions of $t_{\widehat{\rho}}$ and $F_{\widehat{\delta}}$ statistics in finite samples depend on nuisance parameters (Harris and Tzavalis (1996)).

For these reasons, and as it was done in Evans and Karras (1996), critical values are simulated. We will use two simulation methods : Monte-Carlo and Bootstrap.

The simulation procedure consists firstly in estimating parameters of models (step three and four) under the null hypothesis, then in generating for each simulation a panel data set using these parameters. In the Monte-Carlo's method, residuals are drawn from a Gaussian distribution with a variance equal to the estimated historical one for each country. In the Boostrap's method, we realize a resampling of empirical individual residuals. For each simulated panel data set, we apply the fourth step of the convergence procedure and we compute the statistics $t^s_{\widehat{\rho}}$ and $F^s_{\widehat{\delta}}$. The empirical distributions of these two statistics are built after 10000 simulations. Critical thresholds values correspond to quantiles 1%, 5% and 10%. An obvious advantage of Bootstrap is that we do not impose *a priori* a particular distribution of residuals (Gaussian).

Results of these simulations are robust to modifications operated in the choice of initial values for the simulated series (zero, first historical value of the series or resampling of those values).

At the end of the third step, the convergence hypothesis has been tested. Further, in the fourth step, the convergence process is characterized as absolute or conditional. But at this step, we still do not know if the speed of convergence is common for all countries or not. Indeed, the alternative hypothesis of the test performed by Evans and Karras (1996) is $\rho_i < 0, \forall i$. So we will perform in the last section several tests of a common speed of convergence ($\rho_i = \rho, \forall i$). In the case of a common speed of convergence, we propose an unbiased estimate of this parameter.

[8] Proofs are provided in Evans and Karras (1996), p 261-263.

4 Applications

We apply the procedure exposed before to three samples : a sample *EUROPE* of the 15 members of the European Union (1960-1990), a sample *OECD* of 27 countries (1960-1990) and a sample *WORLD* of 86 countries (1960-1990) which extends the study of Evans and Karras (54 countries) [9]. Then we propose an analysis of the fixed effects in the context of conditional convergence. Finally, we test for a common speed of convergence in the European and OECD samples.

4.1 Convergence tests

The results of convergence tests are presented in the following tables. Critical values for the test statistics are calculated using 10 000 simulations with historical initial values for each country.

Convergence Test : Step 3

	$t_{\widehat{\rho}}$	$t_{1\%}$	$t_{5\%}$	$t_{10\%}$
EUROPE				
Bootstrap	-5.64	-6.04	-5.35	-4.90
Monte Carlo	idem	-6.17	-5.41	-5.01
OECD				
Bootstrap	-5.73	-6.06	-5.38	-4.99
Monte Carlo	idem	-6.16	-5.48	-5.13
WORLD				
Bootstrap	-5.52	-8.21	-7.60	-7.12
Monte Carlo	idem	-8.43	-7.82	-7.34

Convergence Test : Step 4

[9] Annual data of per capita GDP at Purchasing Power Parity are issued from Summers and Heston's database. Oil producers and undocumented countries are excluded from the WORLD sample.

	$F_{\widehat{\delta}}$	$F_{1\%}$	$F_{5\%}$	$F_{10\%}$
EUROPE				
Bootstrap	2.59	4.02	3.45	3.11
Monte Carlo	idem	3.87	3.35	3.15
OECD				
Bootstrap	3.22	3.70	3.15	2.87
Monte Carlo	idem	3.63	3.13	2.86

The fifteen countries of European sample are likely to constitute a "convergence club" given their similarities. We expect to accept the hypothesis of convergence for this sample. Indeed, whatever the simulation method considered (Monte-Carlo or Bootstrap), the null hypothesis of non convergence is rejected.

In order to characterize this convergence, we compare the F-statistic of the fourth step to the simulated thresholds. Whatever the simulation method we consider, critical thresholds values for standard levels are higher than the observed statistic. We then conclude to absolute convergence (rejection of H_0).

As far as the *OECD* sample is concerned, in spite of a greater heterogeneity (the sample includes Mexico and Turkey as well as the United States) we also expect that the convergence remains. Indeed, some latecomer countries (Korea, Mexico) joined the OECD because they had converged, at least partially. It may induce here a selection bias as defined by De Long (1988).

At the 5% significance level, we reject the null hypothesis of non convergence, but the hypothesis of absolute convergence is rejected since $F_{\widehat{\delta}} > F_{5\%}$. Then we conclude to conditional convergence in this sample. It will be worth dealing with the fixed effects (*cf.* infra) which describe all unobservable and structural specificities which affect the steady states.

The third sample, *WORLD,* includes much more heterogeneous countries. For such samples, cross section studies generally conclude to the absence of absolute convergence. But it is possible that the convergence is only a conditional one. Nevertheless, using a panel data approach, Harris and Tzavalis (1996) reject conditional convergence hypothesis in a large sample of countries[10].

We conclude to non convergence for our *WORLD* sample : the testing procedure stops at the end of the second step. So, we remark that conditional convergence does not hold if a wider sample than the one studied by Evans and Karras (86 countries in our sample versus 54 in Evans and Karras) is considered. As both conclusions are *sample specific,* differences can not be related to a selection bias problem (De

[10]However, they conclude to convergence over the period 1960 to 1972. But such a sort sample may not be appropriate to study structural processes of convergence.

Long 1988). So, when very different countries are considered, deviations of per capita GDP growth rates from the international average are found to be infinitely persistent.

However, we have to be very careful about the appropriate interpretation of our results and the definition of the convergence hypothesis. Indeed, as it was stressed by Maddala (1997), in panel unit root tests "*the rejection of the null hypothesis does not mean that all series are stationary. Similarly, a non-rejection of the null hypothesis does not mean that all the series are unit-root processes*" (Maddala 1997, page 24). Particularly, in our study, the rejection of the null hypothesis does not necessarily imply that all economies converge.

4.2 Analysis of fixed effects for the OECD sample

Given that the convergence process for *OECD* countries is conditional, we will propose in this section an analysis of the fixed effects which affect the steady states. Indeed, these effects stand for the structural or policy disparities between the countries in the sample.

This analysis intends to estimate the impact of a set of environmental and control variables on the steady states. Under the conditional convergence hypothesis, the unconditional average of $y_{it} - \overline{y}_t$ is given by :

$$y_i - \overline{y} = -\frac{\alpha_i}{\rho_i}$$

Several methods can be used to estimate fixed effects. The first is to consider the model (6). But in this case, the small time dimension of the series implies a lack of robustness of OLS estimates. That's why, in order to obtain more precise fixed effects estimates, we consider the model (7) which is more restrictive, but allows to work with a panel dimension[11].

As in model (7), the small sample OLS estimator of fixed effects (LSDV) is likely to be biased. So, we compute the bias corrected fixed effects using an unbiased estimate of ρ obtained by Bootstrap simulations (cf. the last section). If we note $\widehat{\rho}$ the unbiased estimate of ρ, the fixed effects can be computed as $\widehat{\delta}_i = \overline{\Delta z}_i - \widehat{\rho}\,\overline{z}_{i,-1}$, when $p_i = 0$, $\forall i$ and $\overline{x}_i = (1/N)\sum_{t=1}^{T} x_{it}$, with $x = \{\Delta z_{it},\, z_{it-1}\}$.

As expected, richer countries have steady states among the highest[12]. The Japanese steady state appears notably higher than those of its partners of OECD including USA. On the contrary, Turkey suffers from a structural disadvantage.

[11] An alternative solution would be to estimate fixed effects with the unconstrained model (6) and a bayesian iterative method. See Maddala (1996) for a presentation of these methods.

[12] Estimates are not given here but are available on request.

Such differences must be explained. Indeed, the existence of conditional convergence dynamics is worth noting, only if the main factors which affect this process can be isolated.

Then, we consider 8 control variables : investment rate (INV), government size (GOV, government expenditures divided by GDP), public investment rate (IG), openness rate (OPEN), the school-enrollment ratio in secondary level (SER), the population growth (POP), the male and female schooling (MALE and FEMALE) [13]. Results of our cross section estimates are given in the following table :

Cross Section Analysis of Fixed Effects

Model	C	INV	GOV	IG	SER	$MALE$	POP	$OPEN$	$Adj. R^2$
1	-0.03 (-2.15)	0.07 (2.06)	0.7E-02 (0.17)	0.40 (2.05)	-0.03 (-0.36)	—	-0.11 (-1.47)	-0.8E-3 (-0.16)	0.49
2	-0.03 (-2.02)	0.06 (1.74)	0.5E-2 (-0.10)	0.39 (2.05)	—	0.4E-3 (0.56)	-0.11 (-1.53)	-0.2E-2 (-0.51)	0.50
3	-0.03 (-4.35)	0.07 (2.89)	—	0.39 (2.25)	—	—	-0.10 (-1.75)	—	0.60

Structural disparities of the per capita GDP in the OECD countries are linked to the private investment effort. This is a quite usual finding even if Barro and Sala-i-Martin (1995) do not confirm such a relation. The population growth rate (POP) negatively affects per capita GDP steady states but is only significant at the 5% level in model 3. As concerns the government role, only public investment seems to have a productive effect in the long run in contrast with general public expenditures[14].

Surprisingly, none of our educational variables is significant. The difficulty to built a good proxy of human capital may explain this failure[15]. The lack of cross sectional variability for these variables in the *OECD* sample could be another explanation.

Besides, this study would have been of greater interest if we had applied it to a larger sample including Third World countries. But in our largest sample we

[13] All series are averages by country (1960-1990) except POP, MALE and FEMALE (1960-1985). The series INV, GOV and OPEN are taken from Summers and Heston. and SER is taken from Mankiw, Romer and Weil (1992). The series MALE, FEMALE and POP are taken from Barro et Sala-i-Martin (1995). The public investment rate series are taken from the OECD's database *Economic Outlooks*.

[14] The estimated coefficient for IG is higher than the coefficient of INV. Nevertheless, the contribution of private investments to structural disparities of per capita GDP is nearly the same than the public investments one, once we take into account the relative size of public and private investments.

[15] About difficulties to assess the impact of human capital see Berthélemy, Dessus et Varoudakis (1997).

concluded to the lack of a convergence process. It would be interesting to extend the space of control variables to variables suggested by new growth theories, like for instance, R&D stocks or public capital stocks.

4.3 Test for a common speed of convergence

Another issue of our study is the test for a common speed of convergence. This hypothesis implies that it takes the same time for all countries to converge to their steady states. After introducing heterogeneity *via* fixed effects, we now test for heterogenous AR coefficients.

In the OECD and European samples, we find that countries are converging, but the alternative hypothesis of the Evans and Karras test ($\rho_i < 0, \forall i = 1..N$) does not imply any restriction on the speed of convergence.

So we perform two tests of common speed hypothesis. The first one is a F-test of the null hypothesis $\rho_i = \rho_j\,, \forall\,(i,j)\,, i \neq j$. With $T = 30$, we can not be sure that the distribution of the F statistic $F_{\widehat{\rho}}$ is close to the asymptotic standard in our dynamic panel. So, we use both standard asymptotic and simulated distribution of this statistic.

A second test is proposed by Im, Pesaran and Smith (1995). It is a Hausman (1978) type test based on the difference between the LSDV estimator ($\widehat{\rho}_{FE}$) and the mean group OLS estimator ($\widehat{\rho}_{MG}$) of the parameter ρ. The latter is consistent both under the null of homogeneity and the alternative of heterogeneity, the other is efficient under the null but is inconsistent under the alternative. The statistic is defined by :

$$H_{\widehat{\rho}} = \frac{\left(\widehat{\rho}_{MG} - \widehat{\rho}_{FE}\right)^2}{\widehat{\sigma}^2_{MG}\,\widehat{V}} \tag{9}$$

with

$$\widehat{\sigma}^2_{MG} = \frac{1}{N}\sum_{i=1}^{N}\widehat{\sigma}^2_{\epsilon_i} \tag{10}$$

and

$$\widehat{V} = \frac{1}{N^2}\sum_{i=1}^{N}\left(X_i' H_T X_i\right)^{-1} - \left(\sum_{i=1}^{N} X_i' H_T X_i\right)^{-1} \tag{11}$$

where $X_i' = \left[(y_{i,0} - \overline{y}_0), ..., (y_{i,T-1} - \overline{y}_{T-1})\right]$, and H_t is the LSDV operator used to "sweep out" the individual effects. Under the null, where N and T are sufficiently large, this statistic is distributed as $\chi^2(1)$. The results are given in the following table :

Test for a Common Speed of Convergence

	$H_{\widehat{\rho}}$	$F_{\widehat{\rho}}$	$F^s_{1\%}$	$F^s_{5\%}$	$F^s_{10\%}$
EUROPE	0.30	1.24	2.73	2.10	1.93
OECD	19.5*	2.93*	2.40	2.01	1.82

We observe that the null hypothesis of homogeneity (common speed of convergence) is never rejected for the *EUROPE* sample. As far as the F-test[16] is concerned, the conclusion is robust to the use of asymptotic or simulated distributions. At standard levels of significance, the test performed by Im-Pesaran-Smith also does not reject the null hypothesis of homogeneity. On the contrary, homogeneity is always rejected for the *OECD* sample[17].

Regarding convergence in the three samples, our approach leads to the following conclusions : neither absolute nor conditional convergence in the largest sample (*WORLD*), convergence in growth rates with different speeds for each country in the *OECD* sample, and finally, absolute convergence with a common speed for *EUROPE*. This last case corresponds to the strongest definition of convergence : a common convergence process toward the same level of per capita GDP for all countries.

We now propose two estimates of the common speed of convergence ρ for the sample *Europe* .The first one is the Evans and Karras estimate. Although we have rejected the heterogeneity assumption, we compare it to the M.F.R. (Mixed Fixed and Random Coefficients Model) estimate proposed by Hsiao (1989)[18]. In this method, we suppose that the individual effects are fixed and the autoregressive individual parameters are randomly distributed with a common mean and finite variance covariance matrix.

[16] The statistic is defined by

$$F_{\widehat{\rho}} = \frac{\left[SSR_{FE} - \sum_{i=1}^{N} SSR_{ols_i}\right]}{\sum_{i=1}^{N} SSR_{ols_i}} \left[\frac{N(T-1)-k}{(N-1)}\right]$$

Under the null hypothesis, $F_{\widehat{\rho}}$ follows a $F[N-1, N(T-1)-k]$ where k is the number of right hand side variables.

[17] The star indicates a rejection of the null hypothesis of homogeneity at 1% or less.

[18] We thank a referee for suggesting this estimator.

The estimated speed of convergence given by the Evans and Karras approach is 9.8%. The half-life of convergence, that is to say the time that it takes for half the initial gap to be eliminated, is thus about 7 years. As expected, this result is confirmed by the MFR method : the estimated common mean coefficient, 11.8%, is close to the LSDV estimate[19].

This speed is higher than those generally obtained in cross section studies (2% in Barro and Sala-i-Martin (1995)). But, as it was often stressed, the OLS estimator of the lagged variable's coefficient is downward biased in a dynamic panel with fixed effects (*cf.* Hsiao (1986), Blundell and Smith (1991) and Sevestre and Trognon (1992)). It leads here to over-estimate the speed of convergence.

Because of this source of bias, we also report an adjusted estimate of ρ. The adjusted estimate of ρ is equal to the raw point estimate plus a bias correction term. The bias adjustment is calculated by Bootstrap simulations. We generate 10 000 pseudo samples ($N = 15$, $T = 30$) for different values of ρ, and we replicate the Evans and Karras methodology. Then, we obtain a table[20] which relates true values of ρ (used in building simulated series) to corresponding average estimate. Using this table and linear interpolation, we can calculate an adjusted estimate of ρ. The adjusted value of the common speed of convergence is then equal to 8.39% (8.91% by cubic interpolation). The implied half-life of convergence is about 8 years.

5 Conclusion

Several improvements in stationarity tests in panel data have recently been applied to the test of the convergence hypothesis. Nevertheless these new methods generally do not take advantage of the information about steady state included in fixed effects. First, this paper surveys the different approaches in panel data. We propose two applications based on the Evans and Karras's approach. The first one consists in dealing with the individual structural disparities (fixed effects). The second one is the test of the homogeneity of convergence speeds.

Ours results are very close to those obtained in this literature, but we do not find

[19] We have also applied the MFR method to the *OECD* sample. In this sample, the heterogeneity assumption was not rejected, so MFR estimates an average of individual speeds of convergence, under the hypothesis that all parameters ρ_i are drawn in a common distribution. The results are reported in the following table :

MFR	$\widehat{\rho}$	$\widehat{\sigma}_\rho$
EUROPE	-11.8%	0.0792
OECD	-11.4%	0.1177

[20] Not reported, but available on request.

evidence of a conditional convergence process in the 86 countries sample. Indeed, we conclude to an absolute convergence for the European Union and to a conditional convergence for the *OECD* sample. The extension of the individual dimension with heterogenous countries leads us to reject the hypothesis of convergence, even in its weakest form (conditional convergence).

The hypothesis of a common speed of convergence is rejected except for the European sample. In this case the unbiased estimated value is 8.39%. It implies a half life of convergence of 8 years. Given these results, the study of the fixed effects was only possible for the *OECD* sample. Among the considered variables, only the investment ratio seems to be important as far as the conditional convergence process is concerned.

However, as stated by Maddala (1997), we must be very careful about the appropriate interpretation of these results based on a panel root test[21]. Indeed, in the case of a strong rejection of the convergence hypothesis for one individual series with no rejection for the others, a summary statistics does not make sense. One way to deal with this problem consists in applying tests based on combining independent tests (Im Pesaran Shin 1995, Maddala and Liu 1996), since the relevant information always comes from the individual unit root tests. Another solution may consists in using an heterogenous dynamic model and estimating it by a Bayesian iterative method.

[21] We thank P. Sevestre for this suggestion.

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