Testing for Stochastic and Beta-convergence in Latin American Countries

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Abstract

This paper uses time-series data from nineteen Latin American countries and the U.S. to test for income convergence using two existing definitions of convergence and a new testable definition of β-convergence. Only Dominican Republic and Paraguay were found to pair-wise converge according to the Bernard and Durlauf (1995) definition. More evidence of stochastic convergence exists when allowing for structural breaks using the two-break minimum LM unit root of Lee and Strazicich (2003). The results show greater evidence of convergence within Central America than within South America. Dominican Republic is the only country that complies with the neoclassical conditions of income convergence.

JEL classification: C22; C52; O40; O54.

Keywords: Economic growth; Convergence; Latin America; Time-series.

1. Introduction

One of the most important implications of neoclassical growth models is that they predict cross-country convergence. This has originated a large literature to test the convergence hypothesis, most of it in developed economies. Some important examples that use cross-sectional data are Mankiw, Romer and Weil (1992), Barro (1991), Baumol (1986) and Karras (2008). Using panel data analysis we have Quah (1993), Islam (1995) and Chowdhury (2005), and employing time-series techniques we find Bernard and Durlauf (1995), Li and Papell (1997) and Strazicich, Lee

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and Day (2004).[1] Recent literature has extended convergence concepts beyond income; see for example Konya and Guisan (2008), who investigate convergence in the Human Development Index.

As explained in Carlino and Mills (1993), neoclassical growth models require two conditions for per-capita income convergence. These are that shocks to relative per-capita incomes be temporary (stochastic convergence), and that initially poor regions should catch up with rich regions (β-convergence). This paper uses time-series techniques to test for stochastic convergence and β-convergence in nineteen Latin American countries. To test for stochastic convergence I follow the Carlino and Mills (1993) approach that requires that shocks to income of country i relative to a group average income will be temporary. To test for β-convergence I propose a new testable definition of β-convergence that requires that long-term forecast of output of a relatively poor country equals the *maximum* of a given group of countries at a given time t. Additionally, I test for pair wise convergence as defined in Bernard and Durlauf (1995), which requires that long-term forecast of output of two given countries be equal at a fixed time t.

The definitions of convergence utilized in this paper have natural time series unit root and cointegration analogs. Therefore I use Augmented Dickey Fuller (ADF) unit root tests as a starting point. However, as discussed below, ADF unit root test do not account for the possibility of having structural breaks. As showed in Perron (1989), this leads to ADF test statistics biased towards the non rejection of a unit root process. Moreover, Lee and Strazicich (2003) explain that ADF-type endogenous break unit root test like Zivot and Andrews (1992), Lumsdaine and Papell (1997) and Perron (1997) do not consider the possibility of breaks under the unit root null, which implies that the rejection of the null is rejection of a unit root with breaks and not necessarily the rejection of a unit root. Therefore, additional to the ADF test, I use Lee and Strazicich (2003) two-break minimum Lagrange Multiplier unit root test where the alternative hypothesis unambiguously implies trend stationary.

The main contribution of the present paper is the proposed new time series testable definition of β-convergence. This paper differs from previous literature on convergence in the sense that is the first in testing different notions of convergence focusing in Latin American countries using

[1] For a survey of the convergence literature see Islam (2003).

time series techniques with structural breaks. Maeso-Fernandez (2003) tests for β-convergence in many countries worldwide, including eleven Latin American countries in his analysis, buy our data extends for a longer period, includes nineteen Latin American countries. In addition, I test for other notions of convergence. Most of the previous literature that use a time series approach accounts for breaks using ADF-type endogenous break unit root tests. This methodology has important drawbacks. In this paper I use a recently proposed two-break min LM test.

The paper proceeds as follows. Section 2 presents the definitions of convergence used in this paper. Section 3 describes the data, while Section shows the empirical results. Finally, Section 5 concludes.

2. Convergence in Time Series Analysis

Three convergence definitions are explained in this section. The first two are the Bernard and Durlauf (1995) convergence in output between two countries and the second is the Carlino and Mills (1993) stochastic convergence. For the third I propose a new testable definition for β-convergence that proved to be useful for Latin American countries. Along this paper, I will refer to the Bernard and Durlauf (1995) definition of pair wise convergence as Bernard and Durlauf (1995) convergence.[2]

2.1. Bernard and Durlauf (1995) Convergence

Bernard and Durlauf (1995) convergence in output definition states that countries i and j converge if the long term forecast of output for both countries are equal at a fixed time t:

$$\lim_{k \Rightarrow \infty} E\left(y_{i,t+k} - y_{j,t+k} \middle| I_t\right) = 0 \quad (1)$$

Where I_t denotes the information set at time t. This definition has a natural testable analog in the cointegration literature. If countries i and j converge in output, their outputs must be cointegrated with cointegration vector $[1, -1]$. Further, as explained in Greasley and Oxley (1997), if $y_i - y_j$ contains either a non zero mean or a unit root, then the definition above is violated.

[2] This is Definition 2.1. in Bernard and Durlauf (1995).

2.2. Stochastic Convergence

Carlino and Mills (1993) analyze per capita income of eight geographic regions in the U.S. They define a deviation series as, $Dy_{jt} = \bar{y}_t - y_{jt}$ where y_{jt} is the log per-capita output of the region j and $\bar{y}_t$ is the average income in the U.S. at period t. Then they perform ADF tests to the deviation series. Rejection of the unit root hypothesis gives evidence of stochastic convergence. An analog definition for our case also used in Strazicich, Lee and Day (2004) examines the natural logarithm of the ratio per capita real GDP for each country *i* relative to the group's average as follows:

$$z_{i,t} = log\left(n \cdot PCGDP_{i,t} / \sum_{i=1}^{n} PCGDP_{i,t}\right) \qquad (2)$$

where n is the number of countries in the group. Then unit root tests are carried out on the deviation series $z_{i,t}$.

2.3. β-convergence

This type of convergence applies if a poor country tends to grow faster than a rich one, so the poor country tends to catch up with the rich one in terms of the level of per-capita income (Barro and Sala-i-Martin, 1995). Most of the work that test for β-convergence uses cross country data, e.g., Barro (1991), Baumol (1986) and Karras (2008). Recently some convergence literature, e.g., Maeso-Fernandez (2003), started using time-series data to test for β-convergence. Maeso-Fernandez (2003) compares various countries with respect the U.S., that acts as the leading economy. His analysis is based on how the gap between country *i* and the U.S. evolves over time.

In Latin American countries, however, there is no leading economy. Hence, there is no reference point for poor countries to be compared to and this complicates the typical implementation of a time-series β-convergence test. To address this issue, in this paper I define w_t as the maximum natural logarithm GDP per capita (GDP_{pp}) of the set of countries Ω at a given time *t*. That is:

$$w_t = \max_{i \in \Omega} \left\{ y_{i,t} \right\} \qquad \text{for } t = 1, 2, \ldots, T \qquad (3)$$

$$\Psi = \{ i \in \Omega : y_{i,t} = w_t \text{ for some } t = 1,2,\ldots,T \} \quad (4)$$

where Ψ is the leading group of countries. That is, the countries that at some time t have the highest GDP_{pp} of the whole group Ω. A relatively poor country is then in the complement of group Ψ.

Definition 1. A relatively poor country $i \in \Omega/\Psi$ exhibits β-convergence with respect to the leading group Ψ if the long term forecast of output for country i and the maximum of the leading group are equal at a fixed time t,

$$\lim_{k \Rightarrow \infty} E\left(y_{i,t+k} - w_{t+k} \middle| I_t\right) = 0 \quad (5)$$

This definition will be satisfied if $y_{i,t+k} - w_{t+k}$ is a non negative trend stationary process.

3. Data Description

The data used in this paper are the annual natural logarithm GDP per capita (GDP_{pc}) in 1970 PPP-adjusted dollars. The series go from 1945 to 2000 and considers 19 Latin American countries with both GDP data and population data obtained from Oxford Latin American Economic History Database originally published in Thorp 1998 and updated latter by Ame Berges. For the U.S. the data comes from the Penn World Table (Mark 6.2), documented in Heston, Summers and Aden (2006). The countries considered are Argentina, Bolivia, Brazil, Chile, Colombia, Costa Rica, Dominican Republic, Ecuador, El Salvador, Guatemala, Haiti, Honduras, Mexico, Nicaragua, Panama, Paraguay, Uruguay and Venezuela.

4. Empirical Results

4.1. Stochastic Convergence within groups (no breaks)

To test for stochastic convergence within groups, I first define three groups. The first one consists in all of the nineteen countries, the second considers the ten South American countries; Argentina, Bolivia, Brazil, Chile, Colombia, Ecuador, Paraguay, Peru, Uruguay and Venezuela; and the third group consists on the nine Central America and Caribbean countries; Costa Rica, Dominican Republic, El Salvador, Guatemala, Haiti, Honduras, Mexico, Nicaragua, and Panama. Following Strazicich, Lee and Day (2004), I examine the natural logarithm of the ratio per capita real GDP for each country *i* relative to the group's average as described in equation (2). The results employing bivariate ADF unit root tests are reported in Table 4 in the Annex. The table shows little evidence of stochastic convergence within groups. At 10% confidence level only five countries, Bolivia, Dominican Republic, Guatemala, Mexico and Panama are converging to its region average. When considering stochastic convergence with respect to Latin America, six countries reject the unit root at a 10% significance level.

4.2. Pair wise stochastic convergence with Structural Breaks

In this section I use Bernard and Durlauf (1995) definition of stochastic convergence as presented in equation (1) and I apply it to every possible par of countries. Ignoring the possibility of breaks will bias the analysis towards finding a unit root series, that is, towards finding less convergence. Moreover some popular unit tests with breaks like Zivot and Andrews (1992) and Lumsdaine and Papell (1997) will overestimate convergence levels since they do not consider the possibility of breaks under the null. In this section I propose employing the Lee and Strazicich (2003) minimum LM unit root test that considers two breaks and the Lee and Strazicich (1999) that considers one break.[3] The advantages of these tests, as pointed out in Strazicich, Lee and Day (2004), are that the break points are endogenously determined from the data; the tests are not subject to spurious rejections in the presence of unit root with break(s) and that the alternative hypothesis is true and spurious rejections are absent.

The results for Model C that allows for two brakes in levels and trends are presented in Table 5 in the Annex. The maximum number of lags to correct for serial correlation is k = 8 and lags are being dropped out if they are not significantly different form zero at a 10% confidence level. Each possible combination of T_{B1} and T_{B2} is restricted to be in the interval [0.1T, 0.9T]. When considering for structural breaks and at a 10% significance level the number of pair wise stochastic convergence is 85 of out of 171 possible pair wise relations. This number is larger than when no structural breaks are considered.

[3] The Gauss codes for these tests were obtained from Professor Junsoo Lee, University of Alabama.

4.3. Stochastic Convergence within groups with Structural Break(s)

Following Carlino and Mills (1993) I analyze the series $z_{i,t}$ as defined in equation (2). The groups are the same geographical groups defined before. Its important to notice that if a country has a shock that is of the same magnitude as the average shock to the rest of the countries, this leaves the relative income unchanged. Hence, the structural breaks identified by this methodology imply country specific breaks. First, I allow for two changes in levels, which is Model A as in Perron (1989). The estimation output for both geographical regions is reported in Table 1.

Table 1. Model A: Two Break minimum LM convergence test.

	$\hat{\phi}$	Test statistic	$\hat{k}$	$\hat{T}_{B1}$	$\hat{T}_{B2}$	λ_1	λ_2
Ten South American Countries and the U.S.							
Argentina	-0.630	-4.084[b]	4	1963	1980	0.34	0.64
Bolivia	-0.131	-3.030	8	1970	1988	0.46	0.79
Brazil	-0.087	-2.421	2	1967	1988	0.41	0.79
Chile	-0.132	-1.957	7	1978	1985	0.61	0.73
Colombia	-0.167	-3.486	8	1962	1992	0.32	0.86
Ecuador	-0.135	-2.188	7	1964	1986	0.36	0.75
Paraguay	-0.065	-2.076	6	1979	1989	0.63	0.80
Peru	-0.230	-2.771	2	1982	1988	0.68	0.79
Uruguay	-0.114	-2.857	7	1973	1981	0.52	0.66
Venezuela	-0.046	-1.316	1	1958	1988	0.25	0.79
U.S.	-0.327	-2.423	3	1970	1989	0.46	0.80
Nine Central America and Caribbean Countries and the U.S.							
Costa Rica	-0.106	-1.886	7	1955	1989	0.20	0.80
Dominican Rep.	-0.291	-3.581[a]	7	1964	1989	0.36	0.80
El Salvador	-0.108	-1.939	1	1992	1994	0.86	0.89
Guatemala	-0.175	-5.684[c]	1	1955	1994	0.20	0.89
Haiti	-0.189	-2.687	2	1978	1993	0.61	0.88
Honduras	-0.185	-2.279	0	1968	1988	0.43	0.79
Mexico	-0.513	-4.028[b]	1	1977	1983	0.59	0.70
Nicaragua	-0.072	-2.178	2	1971	1978	0.48	0.61
Panama	-0.116	-2.345	2	1957	1989	0.23	0.80
U.S.	-0.352	-2.182	4	1968	1988	0.43	0.79

Model A allows for two changes in levels. k is the number of lagged first difference terms. T_{Bj} denotes the estimated years for the break points, $\lambda_j=(T_{Bj}/T)$ for j=1, 2. [a], [b], [c] denote the significant at 10%, 5% and 1% respectively. The approximate critical values were obtained for endogenous break from Table 2 in Lee and Strazicich (2003).

Four of nineteen countries converge stochastically at 10% significance level and three reject the unit root null at a 5% level. More evidence of stochastic convergence is found within the Central America and Caribbean group than within South American countries. Within South America, we have only four economies converging. Argentina and Guatemala stochastically converge in both cases; Dominican Republic and Honduras converge to their regions and Colombia and Mexico to the overall Latin American average. Considering only change in levels seems too restrictive, therefore I present Model C, which allows for two structural breaks in both levels and trend. Table 2 presents the estimated output.

Table 2. Model C: Two Break minimum LM convergence test.

	$\hat{\phi}$	Test statistic	$\hat{k}$	$\hat{T}_{B1}$	$\hat{T}_{B2}$	λ_1	λ_2
Ten South American Countries and the U.S.							
Argentina	-1.197	-5.234	5	1969	1988	0.45	0.79
Bolivia	-0.452	-4.992	7	1973	1993[d]	0.52	0.88
Brazil	-0.720	-4.962	6	1971	1988	0.48	0.79
Chile	-0.684	-4.327	8	1970	1987	0.46	0.77
Colombia	-0.802	-5.451[a]	1	1970	1992	0.46	0.86
Ecuador	-0.590	-4.324	7	1964	1986	0.36	0.75
Paraguay	-0.495	-4.045	6	1963	1983[d]	0.34	0.70
Peru	-0.901	-6.076[b]	6	1961[d]	1986	0.30	0.75
Uruguay	-0.679	-4.759	2	1957	1976	0.23	0.57
Venezuela	-0.834	-4.496	5	1960	1981	0.29	0.66
U.S.	-0.627	-4.271	6	1964	1987	0.36	0.77
Nine Central America and Caribbean Countries and the U.S.							
Costa Rica	-0.709	-5.503[a]	6	1956	1981	0.21	0.66
Dominican Rep.	-1.019	-5.950[b]	8	1963	1988	0.34	0.79
El Salvador	-0.503	-4.586	1	1981	1991[d]	0.66	0.84
Guatemala	-0.152	-5.488[a]	1	1979	1994	0.63	0.89
Haiti	-0.650	-4.751	6	1962	1981	0.32	0.66
Honduras	-0.778	-5.415[a]	7	1967	1985	0.41	0.73
Mexico	-1.691	-5.684[a]	5	1974	1984	0.54	0.71
Nicaragua	-1.780	-6.536[c]	7	1977	1987	0.59	0.77
Panama	-0.576	-4.759	4	1958	1991	0.25	0.84
U.S.	-1.253	-4.680	5	1967	1984	0.41	0.71

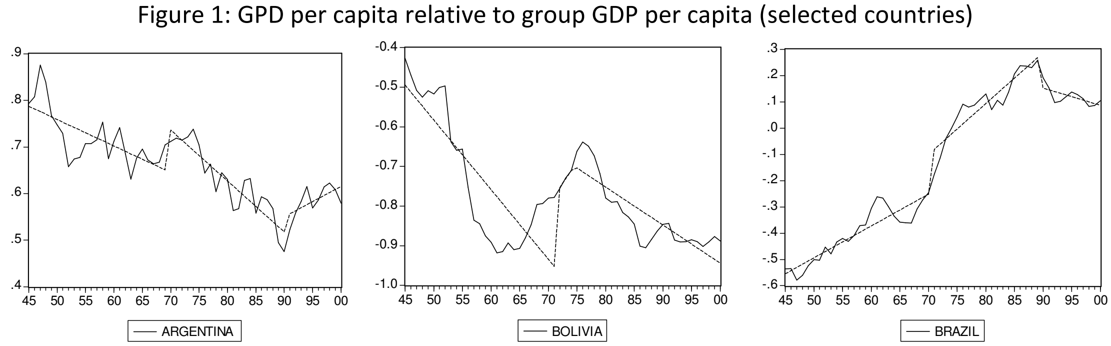
Model C allows for two changes in levels and trend. k is the number of lagged first difference terms. T_{Bj} denotes the estimated years for the break points. [a], [b], [c] denote the significant at 10%, 5% and 1% respectively. [d] denotes that the break is not significant at a 10% level. The approximate critical values were obtained for endogenous break from Table 2 in Lee and Strazicich (2003). For Model C, the critical values depend on $\lambda_j=(T_{Bj}/T)$ for j=1, 2.

When allowing for breaks in the level and trend, we obtain even more evidence for stochastic convergence. Eight of the nineteen countries reject the unit root null at 10% significance level and three at a 5% significance level. Again, more evidence of stochastic convergence is found in Central American and Caribbean countries than in South American countries. Both structural breaks are significant in fourteen of the nineteen countries and in all of the countries we have that at least one of the breaks is significant. As explained before, only country specific shocks are accounted in this process. Therefore, common shock like the oil crisis in the seventies or the debt crisis in the eighties that most likely affected all the countries, do not appear in the analysis. However, country specific shocks like the Argentinean hyperinflation in 1988 or the high tin prices in 1973-75 period (main Bolivian export commodity) appear to be statistically significant.

For comparison purposes and to have a country of reference, I include the GDP of the U.S. in both of the geographical groups and for Model A and Model C to see whether the average of each of the groups converges with the U.S. The results reported in Tables 1 and 2 show that in none of the cases there is convergence, even considering the existence of two endogenous structural breaks.

The estimates in Table 2 show that in four countries; Bolivia, Paraguay, Peru and El Salvador, only one break is significant. For these countries I run a one-break minimum LM unit root test developed in Lee and Strazicich (1999). The results are presented in Table 6 in the Annex. The results from the one-break test are consistent with the two-break test results for El Salvador and Paraguay, but for Bolivia and Peru the results are reversed. To get a more intuitive idea of the how taking into account the breaks affects convergence, I follow Strazicich, Lee and Day (2004) and superimpose the z_t series obtained in equation (2) with a linear trends estimated with OLS for the years of the breaks estimated earlier. These results for the first three countries in the sample are presented in Figure 1 and for the rest of the countries are presented in Figure 4 in the Annex.

Figure 1: GPD per capita relative to group GDP per capita (selected countries)



As can be observed in Figure 1, these three series appear to be stationary when taking into account the estimated structural changes. An important feature of log-time graphs is that its slope reflects the growth of the variable. In this case each series' slope represents the difference between each country GDP per capita PPP-adjusted growth rate and the Latin American's average growth rate. For example, we have that Brasil's GDP_{pc} systematically grew at faster rates than the average in Latin America until late in the eighties. Similar conclusions can be drawn from the other graphs.

4.4. β-convergence

As explained previously, β-convergence implies that poor countries tend to catch up with the rich ones in terms of the level of per-capita income. To test for β-convergence in Latin American countries we use Definition 1, which requires that relatively poor countries converge in output with a leading group of countries. When constructing the variable w_t as the maximum log GDP_{pp} for the set (Ω) of nineteen countries, it was found that the group of leading countries is:

$\Psi =$ {Argentina, Chile, Mexico, Uruguay and Venezuela}

A time-series graph illustrating the evolution of income per capita of this maximum is presented in Figure 2. Uruguay had the highest GDP_{pp} during the 50', Venezuela during the 60' and Argentina in the late 40' and stating on the 70' until 1988. Mexico was the leading economy during the early 90' and Chile from 1995 until the end of the sample period. The other fourteen countries are considered relatively poor according to Definition 1. The test for β-convergence in equation (5) requires first testing whether $y_{i,t+k} - w_{t+k}$ is a stationary process. The convergence test with no breaks and the convergence two-break min LM test results are reported in Table 3.

Figure 2. GPD per capita of the leading countries (natural logarithms)

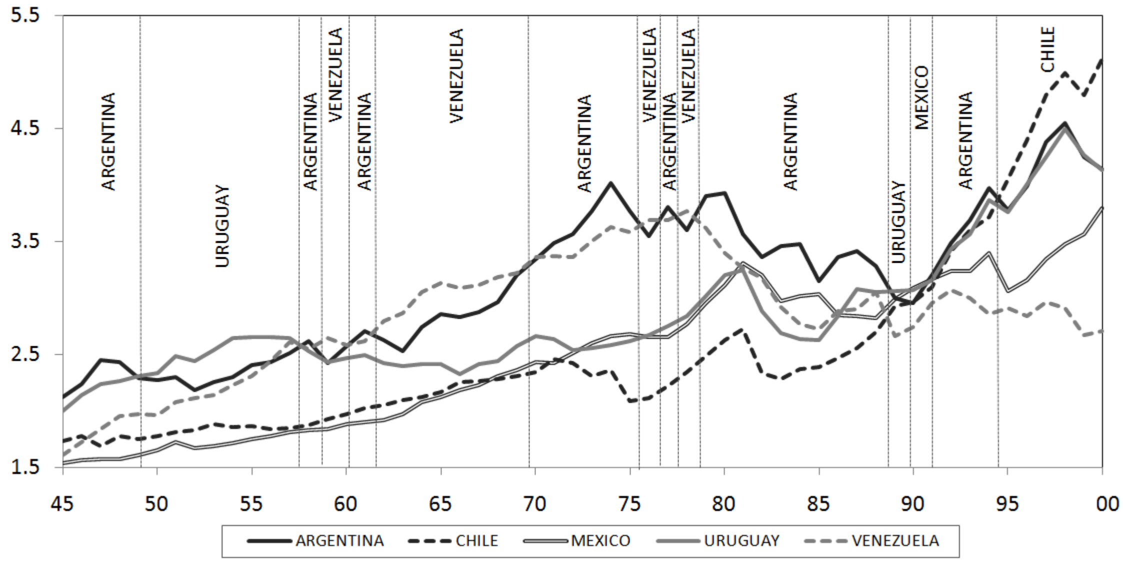


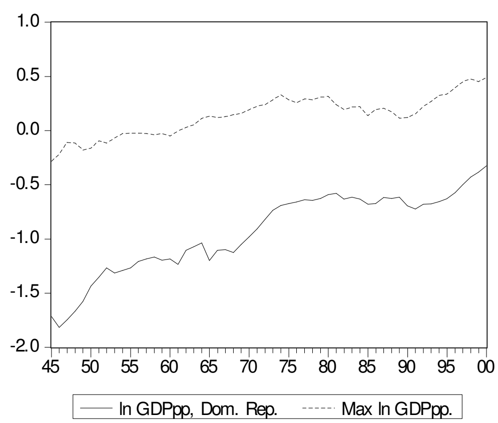
Table 3. Stochastic convergence and β-covergence.

	Min LM Model C				Convergence test with no breaks				
	$\hat{\phi}$ (t-stat)	$\hat{T}_{B1}$	$\hat{T}_{B2}$	$\hat{k}$	τ_τ	ϕ_2	Intercept* (p-value)	Trend** (p-value)	$\hat{k}$
Bolivia	-5.187	1959	1973	6	-2.346	2.054	0.015	0.466	8
Brazil	-4.898	1973	1989	6	-0.265	2.564	0.000	0.000	2
Colombia	-5.408[a]	1973	1986	8	-1.151	0.878	0.180	0.288	3
Costa Rica	-5.084	1955	1985	5	-1.133	1.715	0.201	0.286	1
Dom. Rep.	-5.515[a]	1967	1988	2	-3.470[a]	6.030[b]	0.002	0.013	2
Ecuador	-4.467	1961	1986	8	-0.039	1.420	0.000	0.000	0
El Salvador	-5.678[a]	1980	1989[d]	1	-1.994	1.579	0.030	0.000	3
Guatemala	-5.089	1985	1991	3	-3.004	3.378	0.001	0.100	1
Haiti	-5.164	1976	1990	4	-1.607	1.972	0.068	0.000	2
Honduras	-5.361[a]	1968[d]	1985	4	-2.125	1.842	0.019	0.000	0
Nicaragua	-6.260[b]	1965[d]	1977	5	-1.948	3.461	0.227	0.000	2
Panama	-4.403	1964	1993	5	-2.542	2.251	0.008	0.010	0
Paraguay	-4.517	1966	1985	8	-2.329	1.904	0.015	0.071	4
Peru	-5.978[b]	1958	1988	6	-0.738	2.456	0.453	0.000	5
U.S.	-4.478	1964	1972	6	-0.352	2.338	0.000	0.000	5

Model C allows for two changes in levels and trend. k is the number of lagged first difference terms. For the test with no breaks, lag length chosen by the BIC criterion with a maximum of 8 lags. T_{Bj} denotes the estimated years for the break points. [a], [b], [c] denote the significant at 10%, 5% and 1% respectively. [d] denotes that the break is not significant at a 10% level. The approximate critical values were obtained for endogenous break from Table 2 in Lee and Strazicich (2003). Φ_2 is the F-stat to test $\gamma=\beta=\mu=0$ and τ_τ is the t-stat to test $\gamma=0$. The Φ_2 and τ_τ critical values are from Enders (2004), Table B and A on the Statistical Tables respectively. * denotes the p-values with null for coefficient equal zero and alternative being negative. ** denotes the p-values with null for coefficient equal zero and alternative being positive.

The results show that when allowing for breaks at a 10% significance level six countries converge stochastically to the constructed series w_t. When restricting to the model to have no breaks only Dominican Republic converges stochastically to the w_t series. Our definition of β-convergence further requires that besides stochastic convergence the process should have a non negative trend. This means that the country under analysis should not be diverging from the w_t series. Additionally, we can also test is the intercept coefficient is non positive, which by construction should be. As mentioned earlier, the coefficients on the intercept and trend follow a t-distribution only if we have a stationary process, so that is when stochastic convergence exists. This is true for Dominican Republic that at a 5% significance level has a negative intercept and a positive trend. This is the only economy that satisfies our definition of β-convergence complying with the neoclassical growth model's conditions for income convergence. This implies that shocks to relative Dominican Republic's GDP_{pp} are temporary and that as a poor country is catching up with richer economies. To see graphic intuition of the result, both $y_{Dom.Rep.,t}$ and w_t are shown in Figure 3.

Figure 3. log GDPpp for Dominican Republic
and Max log GDPpp of group Ω.



5. Conclusion

This paper tested for convergence with time-series data from nineteen Latin American countries and the U.S. as a reference country using three testable notions of convergence. The first convergence definition used follows Bernard and Durlauf (1995) and states that two countries converge in output when the long term forecast for both countries equal at a fixed time *t*. The second is known as stochastic convergence and follows Carlino and Mills (1993). The third convergence definition is proposed in this paper and tests for what is known in the economic growth literature as a version of β-convergence. This requires that shocks to a given country are temporary and that a poor country is catching up with richer economies.

The empirical results showed that when testing for pair wise Bernard and Durlauf (1995) convergence only one pair of countries, Dominican Republic and Paraguay, converged from out of 171 possible options pair wise options. When compared with other studies, e.g. Greasley and Oxley (1997) and Maeso-Fernandez (2003), this implies less Bernard and Durlauf (1995) convergence than in other regions of the world. When allowing for structural breaks in the testing for pair wise stochastic convergence, the number of converging pairs was 85 from of out of 171 possible pairs. As pointed out in Perron (1989), this is because the ability to reject a unit root decreases when the stationary alternative is true and structural breaks are ignored. In addition, the two-break min LM unit root test utilized in the paper unambiguously implies trend stationary, overcoming some drawbacks in other convergence studies that were biased towards finding convergence. The paper also tested for stochastic convergence within groups. More evidence of stochastic convergence was found within Central American and Caribbean countries than within South American countries. This was true in all the cases, when no breaks were taken into account, when only changes in levels and with changes in levels and trend. Moreover, when allowing for breaks in stochastic convergence with respect to Latin American average the number of converging countries increased.

One major characteristic of the Latin American countries included in this analysis is that there in no unique leading economy. This implies that there is no reference point to test β-convergence as in Maeso-Fernandez (2003). To overcome this difficulty, this paper proposes an intuitive time-series testable definition of β-convergence. The leading group was found to be formed by Argentina, Chile, Mexico, Uruguay and Venezuela. The results showed that only Dominican Republic was β-converging according to our definition, complying with the neoclassical growth models' conditions for income convergence. This implies that shocks to Dominican Republic real output per capita were temporary and that it is catching up with richer economies

References

Andrade, C., Pinho, C. and Pinho, M. (2010). Exploring regional convergence: Evidence from 19 European countries, 1991-2008. *Applied Econometrics and International Development*, Vol. 10, 87-109.

Barro, R. (1991). Economic growth in a cross section of countries. *Quarterly Journal of Economics*, Vol. 106, 407-443.

Barro, R. and Sala-i-Martin, X. (1995). Economic growth. MIT Press.

Baumol, W. (1996). Productivity growth, convergence and welfare: What the long run data show. *American Economic Review*, Vol. 76, 1072-1085.

Bernard, A.B. and Durlauf, S.N. (1995). Convergence in international output. *Journal of Applied Econometrics*, Vol. 10, 97-108.

Carlino, G. and Mills, L. (1993). Are U.S. regional incomes converging? A time series analysis. *Journal of Monetary Economics*, Vol. 32, 335-346.

Chowdhury, Khorshed. (2005). What's happening to per capita GDP in the ASEAN countries. *Applied Econometrics and International Development*, Vol. 5, 49-68.

Enders, W. (2004). Applied econometric time series. Wiley, 2nd edition.

Greasley, D. and Oxley, L. (1997). Time-series based tests of the convergence hypothesis: Some positive results. *Economic Letters*, Vol. 56, 143-147.

Heston, A., Summers, R. and Aden, B. (2006). Penn World Table, Version 6.2. Center for international comparisons of production, income, and prices at the University of Pennsylvania.

Islam, N. (2003). What have we learnt from the convergence debate? *Journal of Economic Surveys*, Vol. 17, 309-354.

Karras, G. (2008). Growth and convergence, 1950-2003. What can we learn from the Solow model? *Applied Econometrics and International Development*, Vol. 8, 5-18.

Konya, L. and Guisan, M-C. (2008). What does the Human Development Index tell us about convergence? *Applied Econometrics and International Development*, Vol. 9, 5-20.

Lee, J. and Strazicich, M. (1999). Minimum LM unit root test. University of Central Florida Working Paper.

Lee, J. and Strazicich, M. (2003). Minimum Lagrange Multiplier unit root test with two structural breaks. *The Review of Economics and Statistics*, Vol. 85, 1082-1089.

Li, Q. and Papell, D. (1999). Convergence of International Output: Time series evidence for 16 OECD countries. *International Review of Economics and Finance*, Vol. 8, 267-280.

Lumsdaine, R. and Papell, D. (1997). Multiple trend breaks and the unit-root hypothesis. *Review of Economics and Statistics*, Vol. 79, 212-218.

Maeso-Fernandez, F. (2003). A time series approach to β convergence. *Applied Economics*, Vol. 35, 1133-1146.

Mankiw, G., Romer, D. and Weil, D. (1992). A contribution to the empirics of economic growth. *Quarterly Journal of Economics*, Vol. 107, 407-437.

Oyarzun, C. and Araya, I. (2001). Long run dynamics of regional growth in Chile. *Estudios de Economia*, Vol. 28, 69-78.

Perron, P. (1989). The great crash, the oil-price shock and the unit-root hypothesis. *Econometrica*, Vol. 57, 1361-1401.

Perron, P. and Vogelsang, T. (1992). Testing for a unit root in a time series with a changing mean: Corrections and extensions. *Journal of Business & Economic Statistics*, Vol. 10, 467-470.

Quah, D. (1993). Empirical cross-section dynamics in economic growth. *European Economic Review*, Vol. 37, 426-434.

Schmidt, P. and Phillips, P. (1992). LM tests for a unit root in the presence of deterministic trends. *Oxford Bulletin of Economics and Statistics*, Vol. 54, 257-287.

Strazicich, M., Lee, J. and Day, E. (2004). Are incomes converging among OECD countries? Time series evidence with two structural breaks. *Journal of Macroeconomics*, Vol. 26, 131-145.

Thorp, R. (1998). Progress, Poverty and Exclusion: an Economic History of Latin America in the Twentieth Century. Washington DC: Inter-American Development Bank.

Zivot, E. and Andrews, W. (1992). Further evidence on the great crash, the oil-price shock and the unit-root hypothesis. *Journal of Business & Economic Statistics*, Vol. 10, 251-270.

Annex

Table 4. ADF test for stochastic convergence within groups.

	Within Geographical Group*					Latin America**				
	τ_τ	Cons (p-val.)	Trend (p-val.)	ϕ_2	k	τ_τ	Cons (p-val.)	Trend (p-val.)	ϕ_2	k
Argentina[SA]	-2.463	0.035	0.234	3.070	2	-2.824	0.012	0.084	3.948	2
Bolivia[SA]	-3.987[b]	0.000	0.043	5.424[b]	9	-4.354[c]	0.000	0.021	6.616[b]	9
Brazil[SA]	-1.636	0.286	0.269	2.378	2	-1.735	0.280	0.221	2.440	2
Chile[SA]	-0.833	0.367	0.015	2.323	0	-0.858	0.994	0.092	1.288	3
Colombia[SA]	-1.547	0.201	0.189	0.952	0	-1.279	0.575	0.334	0.653	0
Costa Rica[CA]	-2.537	0.007	0.046	2.837	1	-2.127	0.659	0.108	2.431	1
Dom. Rep.[CA]	-4.023[b]	0.004	0.015	6.224[b]	2	-3.420[a]	0.008	0.041	5.203[b]	1
Ecuador[SA]	-0.826	0.677	0.495	1.762	0	-0.916	0.688	0.497	1.838	0
El Salvador[CA]	-2.220	0.536	0.065	1.748	4	-2.147	0.079	0.069	1.601	4
Guatemala[CA]	-4.843[c]	0.951	0.063	11.991[c]	1	-5.312[c]	0.000	0.028	12.492[c]	1
Haiti[CA]	-2.212	0.030	0.022	3.013	2	-2.245	0.028	0.022	2.891	2
Honduras[CA]	-1.652	0.049	0.202	2.121	0	-2.329	0.014	0.057	2.894	0
Mexico[CA]	-3.289[a]	0.001	0.005	4.174	0	-3.312[a]	0.002	0.005	4.128	1
Nicaragua[CA]	-2.322	0.149	0.007	3.043	2	-1.563	0.073	0.023	2.678	0
Panama[CA]	-4.055[b]	0.000	0.000	5.685[b]	1	-3.732[b]	0.012	0.002	4.760[a]	2
Paraguay[SA]	-2.662	0.015	0.129	2.392	4	-2.727	0.016	0.161	2.560	4
Peru[SA]	-1.661	0.431	0.123	1.250	0	-1.979	0.893	0.071	1.653	0
Uruguay[SA]	-0.302	0.859	0.425	0.738	0	-1.051	0.554	0.828	0.974	1
Venezuela[SA]	-3.044	0.000	0.000	9.207[c]	0	-3.401[a]	0.000	0.000	9.718[c]	0

* Denotes convergence within the specific geographical group; SA, South American countries; CA, Central America and Caribbean countries. ** denotes convergence to Latin America average. Lag length chosen by the BIC criterion with a maximum of 5 lags. [a], [b], [c] denote the significant at 10%, 5% and 1% respectively. The t critical values are from MacKinnon one side p-values. The F critical values are from Enders (2004), Table B on the Statistical Tables.

Table 5. Pair wise convergence with LM two-break test, Model C.

	Bolivia	Brazil	Chile	Colombia	Costa Rica	ominican Republi	Ecuador	El Salvador	Guatemala	Haiti	Honduras	Mexico	Nicaragua	Panama	Paraguay	Peru	Uruguay	Venezuela
Argentina	-5.60^{a}	-4.63	-5.99^{b}	-4.78	-5.82^{b}	-5.75^{b}	-4.23	-6.03^{b}	-4.49	-4.95	-5.17	-5.79^{b}	-5.95^{b}	-4.51	-7.43^{c}	-6.28^{b}	-5.19	-6.32^{b}
Bolivia		-5.91^{b}	-5.22	-4.89	-5.61^{a}	-4.63	-4.72	-5.22	-7.00^{c}	-5.20	-5.09	-5.28	-4.49	-4.24	-5.96^{b}	-4.62	-6.20^{b}	-4.20
Brazil			-5.74^{b}	-6.12^{b}	-6.52^{c}	-6.85^{c}	-4.95	-5.48^{a}	-4.86	-5.47^{a}	-5.53^{a}	-5.99^{b}	-5.11	-5.12	-6.47^{c}	-5.56^{a}	-4.46	-4.64
Chile				-4.69	-6.87^{c}	-5.31^{a}	-4.06	-6.18^{b}	-4.64	-6.46^{c}	-5.63^{a}	-5.64^{a}	-6.70^{c}	-5.39^{a}	-5.86^{b}	-6.30^{b}	-4.78	-4.63
Colombia					-4.40	-5.33^{a}	-5.61^{a}	-5.47^{a}	-4.96	-6.42^{c}	-4.62	-6.84^{c}	-4.87	-4.69	-5.03	-6.24^{b}	-5.25	-5.22
Costa Rica						-4.94	-4.16	-5.33^{a}	-4.66	-6.89^{c}	-5.11	-4.48	-4.96	-5.03	-6.47^{c}	-5.04	-4.98	-5.08
Dom. Rep.							-5.72^{b}	-5.68^{b}	-7.27^{c}	-5.31^{a}	-4.61	-5.16	-5.36^{a}	-5.38^{a}	-5.22	-4.93	-5.65^{a}	-6.38^{c}
Ecuador								-5.93^{b}	-6.46^{c}	-5.37^{a}	-4.48	-4.27	-4.50	-4.29	-5.70^{b}	-5.27	-5.44^{a}	-4.88
El Salvador									-7.81^{c}	-4.57	-6.01^{b}	-6.68^{c}	-5.14	-4.62	-4.95	-5.69^{b}	-5.08	-5.90^{b}
Guatemala										-5.45^{a}	-4.52	-4.98	-5.60^{a}	-3.82	-4.21	-5.40^{a}	-5.50^{a}	-4.90
Haiti											-4.92	-4.65	-5.83^{b}	-5.05	-5.32^{a}	-5.75^{b}	-5.44^{a}	-3.91
Honduras												-5.91^{b}	-7.56^{c}	-5.15	-10.83^{c}	-6.07^{b}	-5.28	-5.42^{a}
Mexico													-7.78^{c}	-5.21	-5.60^{a}	-5.67^{a}	-4.44	-4.02
Nicaragua														-4.88	-6.06^{b}	-7.46^{c}	-5.32^{a}	-4.96
Panama															-3.98	-5.35^{a}	-4.30	-4.16
Paraguay																-5.37^{a}	-4.58	-4.79
Peru																	-4.79	-5.61^{a}
Uruguay																		-5.36^{a}

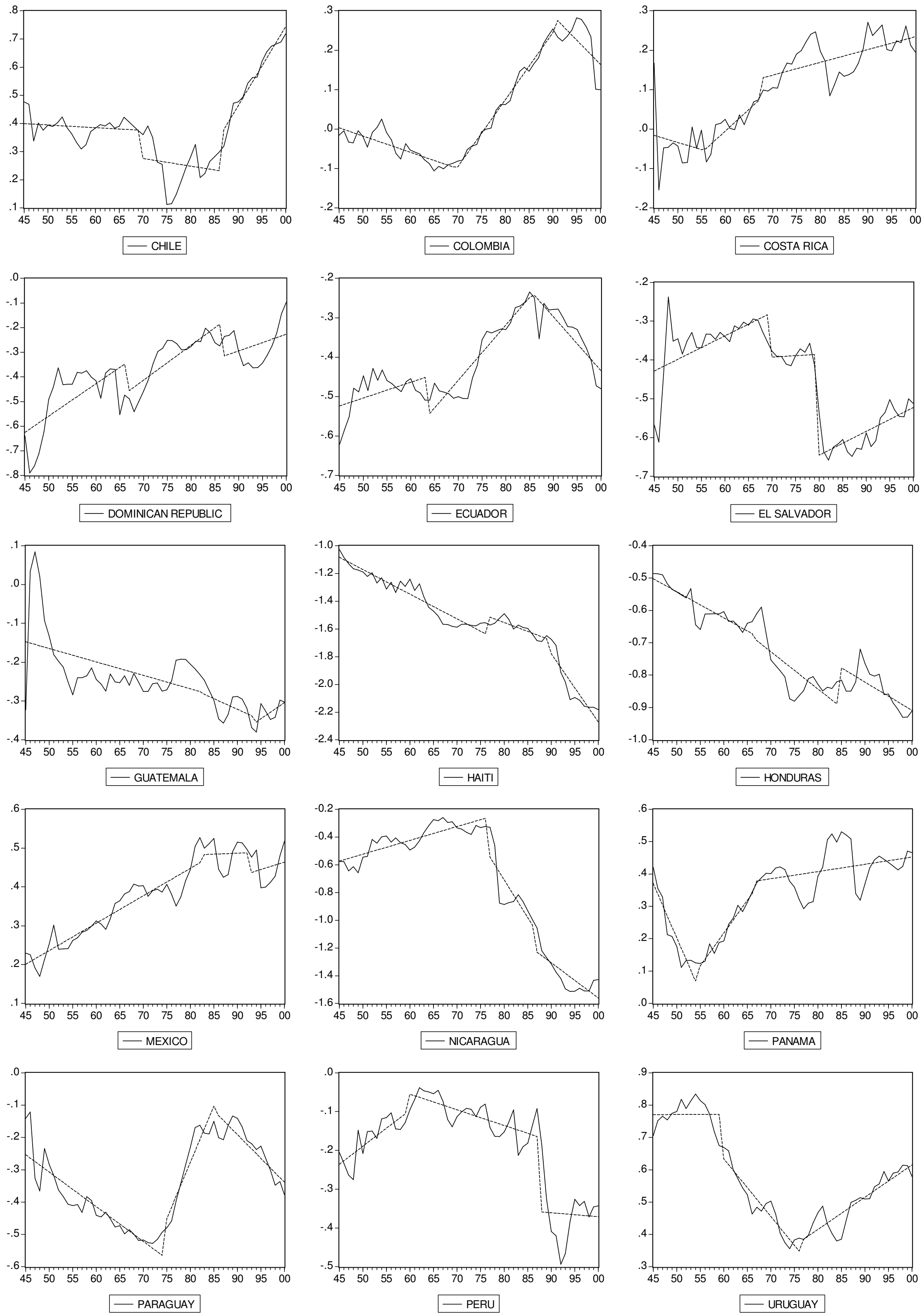
The figures reported are min t-statistics. Model C allows for two changes in levels and trend. ^{a}, ^{b}, ^{c} denote significant at 10%, 5% and 1% respectively. The approximate critical values were obtained for endogenous break from Table 2 in Lee and Strazicich (2003). For Model C, the critical values depend on the years of the breaks.

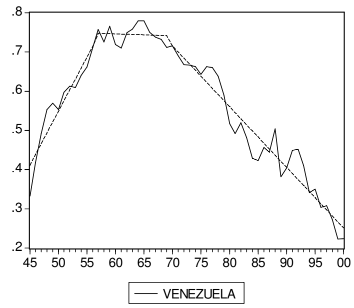
Table 6. Model C: One Break minimum LM unit root test.

	$\hat{\phi}$	Test statistic	$\hat{k}$	$\hat{T}_B$	λ
South American Countries					
Bolivia	-0.367	-4.933^{b}	8	1971	0.48
Paraguay	-0.199	-3.360	6	1957	0.23
Peru	-0.316	-3.744	2	1986	0.75
Central America and Caribbean Countries					
El Salvador	-0.095	-1.917	1	1994	0.89

Model C for one change in levels and trend. k is the number of lagged first difference terms. T_B denotes the estimated year for the break point. ^{a}, ^{b}, ^{c} denote the significant at 10%, 5% and 1% respectively. The approximate critical values were obtained from Table 2 in Strazicich, Lee and Day (2004). For Model C, the critical values depend on $\lambda=(T_B/T)$.

Figure 4. GPD per capita relative to group GDP per capita (natural logarithms)

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