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REGIONAL ECONOMIC GROWTH AND CONVERGENCE, 1950-2007:

Some Empirical Evidence

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Abstract

This paper investigates and compares the experience of several geographic regions with economic growth and convergence in income per capita. Income per capita is correlated positively with saving rates and negatively with population growth rates, though the explanatory power of these two variables varies by region. The empirical findings are broadly supportive of conditional convergence at an estimated average annual rate that has ranged from 0.8% in Europe to 1.7% in Asia. It is also shown that the speed of convergence is far from constant over time: it has been steadily falling in the OECD and the Americas, but steadily increasing in Asia.

JEL classification: O40.

Keywords: Solow Growth Model, Economic Growth, Convergence.

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1. Introduction

This paper investigates and compares the experience of several geographic regions with economic growth and convergence in income per capita using the Solow (1956) model of economic growth. The Solow model is one of the most widely used models in economics. Its usefulness and popularity are easily demonstrated by the extremely wide range of economic and other applications which employ it as a building block.[1]

Not surprisingly, a substantial amount of empirical research has been devoted to the investigation of the validity of the Solow model's predictions. The most influential of these studies is the contribution by Mankiw, Romer, and Weil (1992), who concluded that the empirical evidence is strongly consistent with (a somewhat modified) Solow model.[2]

The present paper uses the Mankiw, Romer, and Weil (1992) methodology in order to examine economic growth and convergence in several geographical regions since 1950, and compare it to the experience of the rest of the world.

First, the paper tests the predictions of the Solow model for the full sample (WORLD), as well as for the regions of AFRICA, the AMERICAS, ASIA, EUROPE, and the subsamples of OECD and non-OECD countries, all over 1950-2007. The empirical results suggest that Solow's theoretical predictions are largely consistent with the data: the standard of living is correlated positively with saving rates and negatively with population growth rates.

Next, the paper's empirical evidence is strongly supportive of *conditional* (though not of *absolute*) convergence, not just in the WORLD sample, but for each of the geographic regions examined. This implies that countries may be generally approaching different steady states, but when saving and population growth rates are taken into account, there is convergence at an estimated rate of 0.8% (in EUROPE) to 1.7% (in ASIA) a year.

Finally, the paper estimates time-varying convergence rates for all data sets. The main findings are that the speed of convergence varies significantly over time, but in ways that differ substantially across regions. Thus, convergence rates are shown to have steadily decreased in the OECD and the AMERICAS, while they have steadily increased in ASIA.

The rest of the paper is organized as follows. The empirical methodology is outlined in section 2, while section 3 discusses the data sources and definitions. The empirical results are presented and discussed in section 4. Section 5 concludes.

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[1] Consider, for example, the following three recent working papers in areas as diverse as business-cycles (Arias, Hansen, and Ohanian, 2006), environmental economics (Brock and Taylor, 2004), and health and development (Acemoglou and Johnson, 2006).

[2] These results, however, have been challenged by Bernanke and Gurkaynak (2001), who argue that an alternative class of growth models, the so-called endogenous growth models, are more consistent with the data. See Romer (1990) and Rebelo (1991) for two of the leading endogenous growth models. Aghion and Howitt (1998) present an excellent survey.

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2. Empirical Methodology

The methodology follows the approach of Mankiw, Romer, and Weil (1992). Assume that the production function is given by the Cobb-Douglas specification

$$Y_t = K_t^{\beta}\left[A_t N_t\right]^{1-\beta}, \tag{1}$$

where Y is output, K is the capital stock, A captures the level of technology, N is employment, and $0 < \beta < 1$. Exogenous growth rates for N and A are given by $\dot{N}_t / N_t = n$ and $\dot{A}_t / A_t = a$, where a dot indicates a time derivative. A standard assumption of the Solow (1956) model is that a constant fraction of income, s, is saved ($0 < s < 1$). Mankiw, Romer and Weil (1992) show that this implies that the level of income per capita at the steady state will be given by:

$$\ln\left(\frac{Y}{N}\right) = a + \frac{\beta}{1-\beta}\ln(s) - \frac{\beta}{1-\beta}\ln(n) + \varepsilon, \tag{2}$$

where ε is an error term. This will form the basis of our first cross-sectional estimated equation:

$$\ln\left(\frac{Y}{N}\right)_i = \gamma_0 + \gamma_1 \ln(\bar{s}_i) + \gamma_2 \ln(\bar{n}_i) + \varepsilon_i, \tag{3}$$

where i is indexing over countries and a bar will indicate country-specific average values over a certain time period. Thus, $\bar{s}$ is the average saving rate, $\bar{n}$ the average population growth rate, and the γ's are the parameters to be estimated. Simple inspection of (2) and (3) establishes the Solow model's predictions: $\gamma_0 > 0$, $\gamma_1 > 0$ (so that a higher saving rate raises the steady-state level of per capita income), and $\gamma_2 < 0$ (so that a higher population growth rate reduces the steady-state level of income per capita).

The Solow framework can also be used to investigate the speed of convergence to the steady state. Letting $y_t \equiv Y_t / N_t$ denote per capita income, and λ be the convergence rate, the model also implies:

$$\ln(y_T) - \ln(y_0) = \left(1 - e^{-\lambda T}\right)\ln\left(y^{ss}\right) - \left(1 - e^{-\lambda T}\right)\ln(y_0). \tag{4}$$

Testing for unconditional (or, "absolute") convergence, we start by assuming that the steady-state values are the same for each country. Then equation (4) can be written in regression format as

$$\left[\ln(y_T) - \ln(y_0)\right]_i = \theta_0 + \theta_1 \ln(y_0)_i + \upsilon_i, \tag{5}$$

where θ_0 is a constant, the slope coefficient is $\theta_1 = -\left(1 - e^{-\lambda T}\right)$, and υ is the error term. Note that a positive (negative) λ implies a negative (positive) θ_1. Absolute convergence (θ_1 < 0) then means that the higher an economy's income per capita is at the beginning of the period, the lower its growth rate will be over the subsequent time period. In other words, poor countries will grow faster than rich ones, closing the gap at the annual rate λ. Of course, if θ_1 is positive, the implied λ is negative, so that the poor are growing more slowly than the rich: there is divergence.

More realistically, however, countries do not all converge to the same income per capita, because the fundamental determinants of their steady states are not identical. Conditional convergence allows these steady-state values in equation (4) to differ. Substituting from (2), equation (4) can now be written in regression format:

$$\left[\ln\left(y_T\right) - \ln\left(y_0\right)\right]_i = \phi_0 + \phi_1 \ln\left(y_0\right)_i + \phi_2 \ln(\bar{s}_i) + \phi_3 \ln(\bar{n}_i) + \nu_i , \qquad (6)$$

where ϕ_0 is a constant, $\phi_1 = -\left(1 - e^{-\lambda T}\right)$, ν an error term, and the Solow model still predicts ϕ_2 > 0 and ϕ_3 < 0. Once again, ϕ_1 is negative (positive) if λ is positive (negative). But a negative ϕ_1 implies *conditional* convergence: a country that is further away from its steady state will experience faster growth than a country that is closer to its steady state, but there is no guarantee that the two countries are converging to the same steady state (the steady states will be the same only if ϕ_2 = ϕ_3 = 0). Note that the Solow model actually predicts conditional (but not necessarily absolute) convergence.

Finally, we will allow for a time-varying conditional convergence parameter, λ_t, by estimating equation (6) for a number of rolling, overlapping windows of length *k*. This way we can investigate how the speed of convergence has changed over time.[3]

3. The Data

All data are obtained from the Penn World Table (PWT, Mark 6.3), documented in Heston, Summers, and Aden (2009; see also Summers and Heston, 1991).

The WORLD data set consists of the 62 economies for which data on all series exist for each year of the 1950-2007 period. The variable *y* is measured as real GDP per capita (*rgdpch*) expressed in PPP terms, the variable *s* is measured by the investment share of real GDP (*ki*), and the variable *n* is measured by the growth rate of population (*pop*).

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[3] One can also estimate time-varying absolute convergence parameters following the same technique on regression (6). As our objective here is to evaluate the Solow model, however, we skip this exercise and focus on conditional convergence.

The Appendix presents the list of these countries and the average growth rate of GDP per capita for each country over 1951-2007. As can be seen form the table, the average annual growth rate of per capita GDP has varied from –1.65% in Congo to 5.97% in China.

In addition to this WORLD data set of 62 economies, we also consider a number of regional data sets. AFRICA includes Congo, Egypt, Ethiopia, Kenya, Mauritius, Morocco, Nigeria, South Africa, and Uganda (9 countries); AMERICAS consists of Argentina, Bolivia, Brazil, Canada, Chile, Colombia, Costa Rica, Dominican Republic, Ecuador, El Salvador, Guatemala, Guyana, Honduras, Mexico, Nicaragua, Panama, Paraguay, Peru, Puerto Rico, Trinidad and Tobago, United States, Uruguay, and Venezuela (23 countries); ASIA includes China, India, Israel, Japan, Pakistan, the Philippines, Sri Lanka, Taiwan, and Thailand (9 economies); EUROPE consists of Austria, Belgium, Cyprus, Denmark, Finland, France, Greece, Iceland, Ireland, Italy, Luxembourg, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, and the United Kingdom (19 economies); as well as OECD (23 economies) and non-OECD (39 economies) data sets.

4. Empirical Results and Discussion

Table 1 reports estimated versions of equation (3), one for the WORLD data set and one for each of the six regional data sets. Beginning with the first column of Table 1 for the WORLD data set, the estimated coefficients of the investment rate and the population growth rate are γ_1 = 1.058 and γ_2 = –0.716, respectively. They both have the expected signs and are highly statistically significant. Note that these two explanatory variables alone account for two-thirds of the sample's variability in per capita income (R^2 = 0.651).

The remaining columns of Table 1 repeat the estimation for the regional data sets. With a single exception, all of the estimated γ_1 and γ_2 coefficients have the expected signs,[4] and are generally statistically significant. The estimated γ_1's range from 0.900 for non-OECD to 1.672 in ASIA (both highly statistically significant). The estimated γ_2's vary from (a statistically insignificant) –0.097 for non-OECD to (a highly statistically significant) –2.825 for AFRICA. The joint explanatory power of the two variables in this specification ranges from one quarter in the OECD (R^2 = 0.249) to more than eight-tenths in AFRICA (R^2 = 0.815).

The estimation is, therefore, statistically successful: as predicted by the Solow model, the level of income per capita is raised by an increase in the investment rate and reduced by a higher population growth rate.

Next we investigate convergence. Table 2 reports evidence on absolute convergence, estimating equation (5). For some Data Sets, such as the OECD and non-OECD, AMERICAS, ASIA, and EUROPE the estimated θ_1 is negative, though it is statistically significant only in the OECD. On the contrary, for the WORLD and

[4] The single exception is the negative estimate for γ_1 for the AMERICAS, which however is not statistically significant.

AFRICA the estimated θ_1 is positive, though statistically significant only for AFRICA. This suggests that the only statistically significant evidence from Table 2 points to *absolute* convergence for the OECD economies and *absolute* divergence in AFRICA. This is an interesting finding in itself but provides no information on the validity of the Solow model, because that model's prediction concerns conditional, and not absolute, convergence.

Conditional convergence is tested in Table 3, which reports the results of estimating equation (6). Note first that the signs of starting income, the investment rate, and population growth are as predicted by the Solow model: $\phi_1 < 0$, $\phi_2 > 0$, and $\phi_3 < 0$, in all data sets.

Beginning again with the first column of Table 3 for the WORLD data set, the estimated coefficients of the investment rate and the population growth rate are $\phi_2 = 1.001$ and $\phi_3 = -0.432$, respectively. They not only have the expected signs, but are also highly statistically significant. In addition, the coefficient of starting income, $\phi_1 = -0.488$, is negative and statistically significant, which means there is evidence in favor of *conditional* convergence: controlling for the determinants of the steady state ($\bar{s}$ and $\bar{n}$), the poorer an economy was in 1950, the faster it grew in 1950-2007. In other words, the further away the economy is from its steady state, the faster it grows towards it – though economies do not all converge to the same steady state. This of course is also reflected in the positive value of the implied λ (0.0117), which suggests that (conditional) convergence has been taking place at the annual rate of 1.17%. Note that these three explanatory variables alone account for six-tenths of the WORLD data set's variability in per capita growth ($R^2 = 0.597$).

The rest of the columns of Table 3 repeat the conditional convergence regressions for the regional data sets. Without exception now, all of the estimated ϕ_1, ϕ_2, and ϕ_3 coefficients have the expected signs, and are generally statistically significant. The estimated ϕ_2's range from (a statistically insignificant) 0.706 for the AMERICAS to (a highly statistically significant) 1.172 in ASIA; while the estimated ϕ_3's vary from –0.145 for the OECD to –2.268 for AFRICA (both statistically significant).

Moreover, the estimated ϕ_1's range from –0.377 for EUROPE to –0.622 for the non-OECD (both statistically significant). The implied λ's suggest that (conditional) convergence has been taking place in all regions at an annual rate that varies from 0.83% in EUROPE to 1.71% in the non-OECD.[5]

Finally, we allow for time-varying (conditional) convergence rates, estimating rolling versions of equation (6) for windows of length *k* years, as described above. We consider values of $k = 10$, 15, and 20 years. Figures 1 through 7 report the estimated convergence rates for the seven data sets for each of the three values of *k* and clearly demonstrate that the convergence rate has been far from constant over time.

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[5] The joint explanatory power of the three variables in this specification ranges from four-tenths in ASIA ($R^2 = 0.413$) to more than three quarters in the OECD ($R^2 = 0.763$).

Beginning with Figure 1, the convergence rate for the WORLD data set was hovering between 0.5% and 1% until the mid-1980s, when it increased temporarily to almost 2%, before falling to virtually zero by the early 2000s. Clearly, therefore, the time variation of the convergence parameter, λ, can be very sizable. This means that ignoring it, as in the pure cross-sectional approach of equation (6) and Table 3, can lead to oversimplified results. For example, the λ = 1.17% "average" value for the WORLD data set in Table 3 masks the very interesting evolution of λ_t shown in Figure 1.

Even this, however, does not fully capture the degree of variation that exists across different regions. Figures 2 – 6 show that the speed of convergence has evolved very differently over time across the regions. Thus, convergence rates in the OECD (Figure 2), the Americas (Figure 5), and EUROPE (Figure 7) have steadily declined over time from values that were often substantial (such as 3% in the OECD) to virtually zero (OECD and EUROPE) or even negative rates (the AMERICAS).

In sharp contrast, the experience of ASIA (FIGURE 6) suggests the exact opposite pattern: convergence rates in that region have steadily increased over time, from very low (or negative) values to more than 3% in the 2000s. On the other hand, the speed of convergence has been steady and positive most of time for AFRICA, but with significant gyrations since the mid-1990s. Finally, the non-OECD group mimics the WORLD behavior very closely.[6]

6. Conclusions

This paper investigated economic growth and convergence in per capita income globally, as well as in several regions, using the Solow model and the empirical methodology of Mankiw, Romer, and Weil (1992). The data set consists of 62 countries and covers the period 1950-2007.

The empirical results support the following conclusions:

(i) The standard Solow model's predictions are generally consistent with the data: the standard of living is correlated positively with investment rates and negatively with population growth rates. However, the overall strength of these relationships is higher in the WORLD data set, as well as in AFRICA and ASIA, where just these two variables explain jointly six- to eight-tenths of the sample's cross-country variation in income per capita.

(ii) The empirical findings are supportive of *conditional* convergence for the WORLD data set and for all the regions examined. This implies that countries may be generally approaching different steady states, but when saving and population growth rates are taken into account, there has been convergence at an estimated average annual rate that has ranged from 0.8% (in EUROPE) to 1.7% (in ASIA).

(iii) Allowing for time-varying convergence rates, it is shown that the speed of convergence has been far from constant over the 1950-2007 period. In particular, convergence rates have been steadily falling in the OECD and the AMERICAS, while they have steadily increasing in ASIA.

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[6] We note that these results are quite robust to the choice of *k*.

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Table 1: The Standard Solow Model

		Regions					
	WORLD	OECD	nonOECD	AFRICA	AMERICAS	ASIA	EUROPE.
CONSTANT	7.986**	11.310**	7.647**	0.891	4.121*	10.212**	10.167**
	(0.932)	(0.658)	(1.490)	(1.804)	(1.876)	(1.707)	(1.000)
ln(*I*/*GDP*)	1.058**	1.103*	0.900**	1.356**	-0.454	1.672**	1.057*
	(0.290)	(0.589)	(0.296)	(0.448)	(0.766)	(0.449)	(0.534)
ln(*n*)	-0.716**	-0.097	-0.703*	-2.825**	-1.100**	-0.375	-0.296
	(0.120)	(0.151)	(0.370)	(0.366)	(0.411)	(0.268)	(0.199)
R^2	0.651	0.249	0.453	0.815	0.272	0.600	0.321
N	62	23	39	9	23	9	19

Notes. Dependent variable: logarithm of GDP per capita in 2007. Estimated heteroskedasticity-consistent (White, 1980) standard errors in parentheses. **:significant at 1%, *:significant at 5%.

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Table 2: Testing *Unconditional* Convergence

		Regions					
	WORLD	OECD	nonOECD	AFRICA	AMERICAS	ASIA	EUROPE.
CONSTANT	0.576	5.396**	2.061	-1.874	1.642	2.470	4.573**
	(1.036)	(1.629)	(1.542)	(1.323)	(1.432)	(2.047)	(1.638)
ln(y_0)	0.081	-0.435**	-0.130	0.324*	-0.080	-0.086	-0.337
	(0.120)	(0.182)	(0.189)	(0.153)	(0.169)	(0.263)	(0.185)
implied λ	-0.0014	0.0100	0.0025	-0.0049	0.0015	0.0016	0.0072
R^2	0.009	0.404	0.011	0.072	0.007	0.007	0.312
N	62	23	39	9	23	9	19

Notes. Dependent variable: log difference of GDP per capita, 1951-2007. Estimated heteroskedasticity-consistent (White, 1980) standard errors in parentheses. y_0 represents GDP per capita in 1951. **:significant at 1%, *:significant at 5%.

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Table 3: Testing *Conditional* Convergence

		Regions					
	WORLD	OECD	nonOECD	AFRICA	AMERICAS	ASIA	EUROPE.
CONSTANT	4.973**	5.907**	4.111*	-0.501	2.128	6.075	5.433**
	(1.160)	(0.712)	(1.784)	(1.916)	(1.972)	(3.647)	(0.567)
$\ln(y_0)$	-0.488**	-0.416**	-0.622**	-0.609**	-0.453**	-0.618	-0.377**
	(0.102)	(0.082)	(0.150)	(0.228)	(0.150)	(0.333)	(0.102)
$\ln(I/GDP)$	1.001**	1.099**	0.956**	1.138*	0.706	1.172*	1.015**
	(0.212)	(0.191)	(0.241)	(0.515)	(0.434)	(0.550)	(0.112)
$\ln(n)$	-0.432**	-0.145**	-0.903**	-2.268**	-0.942**	-0.531**	-0.148*
	(0.091)	(0.045)	(0.281)	(0.334)	(0.330)	(0.187)	(0.072)
implied λ	0.0117	0.0094	0.0171	0.0165	0.0106	0.0169	0.0083
R^2	0.597	0.763	0.580	0.656	0.382	0.413	0.721
N	62	23	39	9	23	9	19

Notes: See Table 3.

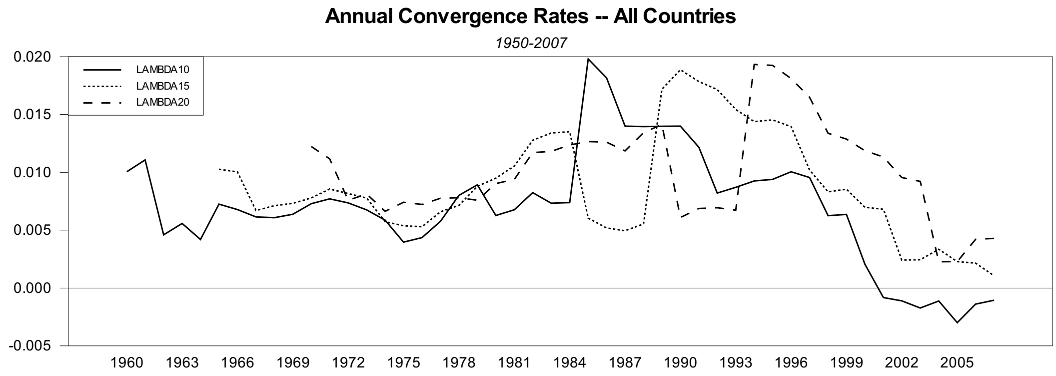

Figure 1: Convergence Rates over time – WORLD

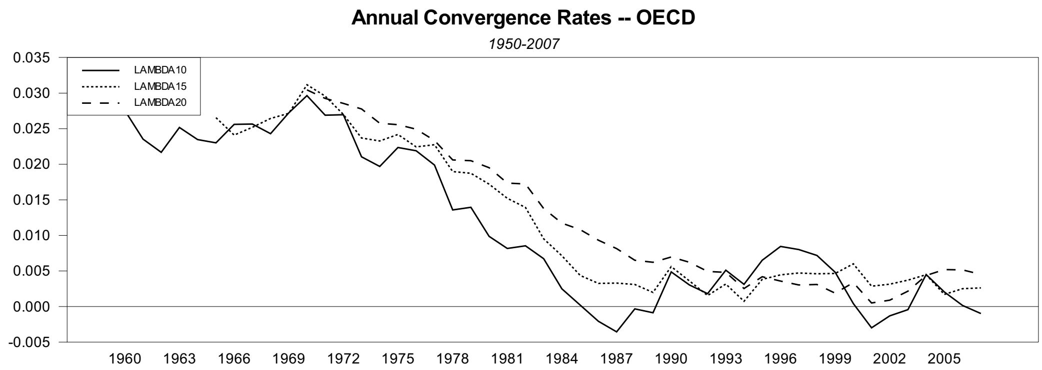

Figure 2: Convergence Rates over time – OECD

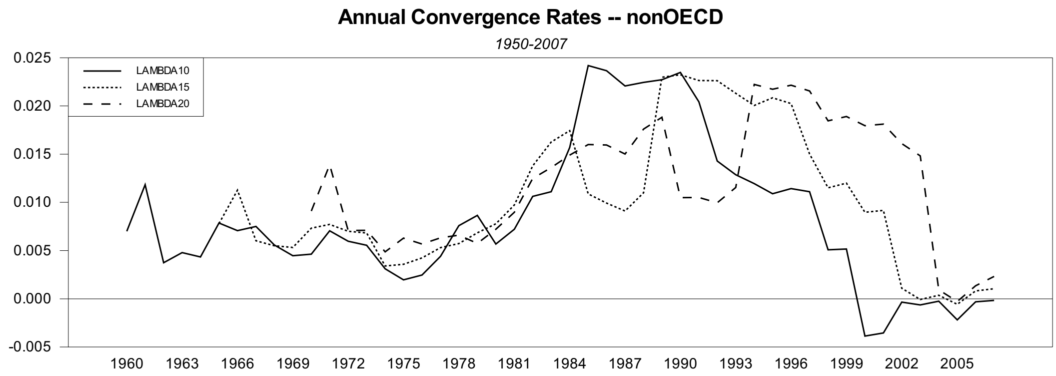

Figure 3: Convergence Rates over time – nonOECD

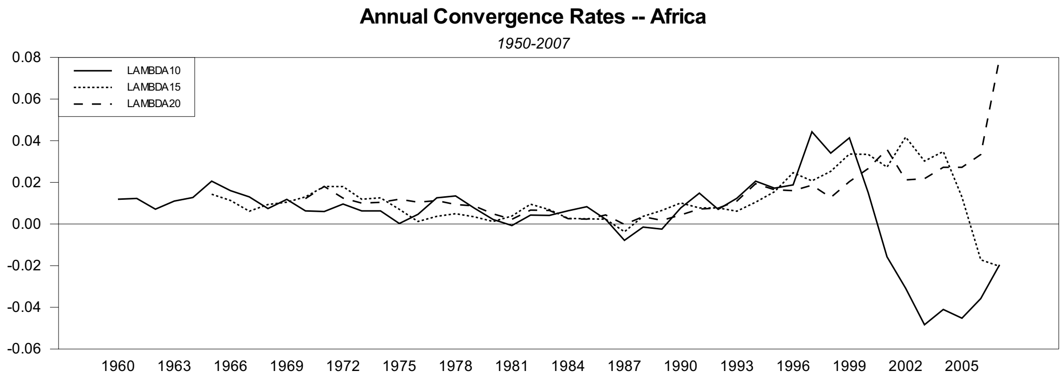

Figure 4: Convergence Rates over time – AFRICA

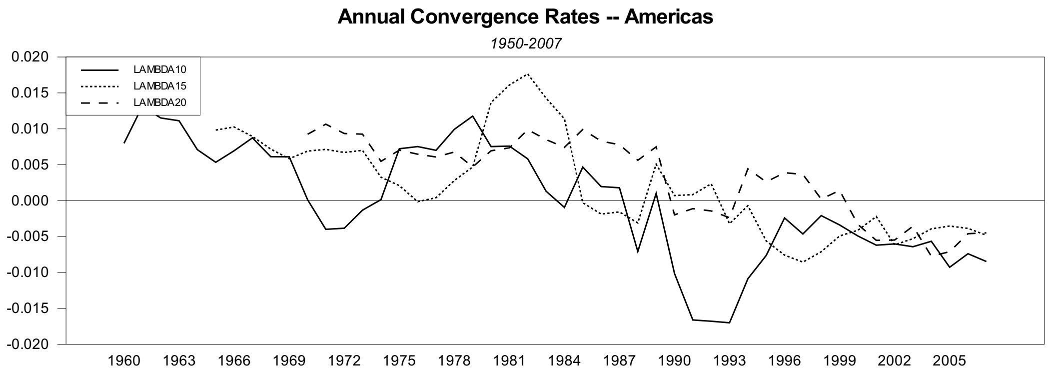

Figure 5: Convergence Rates over time – AMERICAS

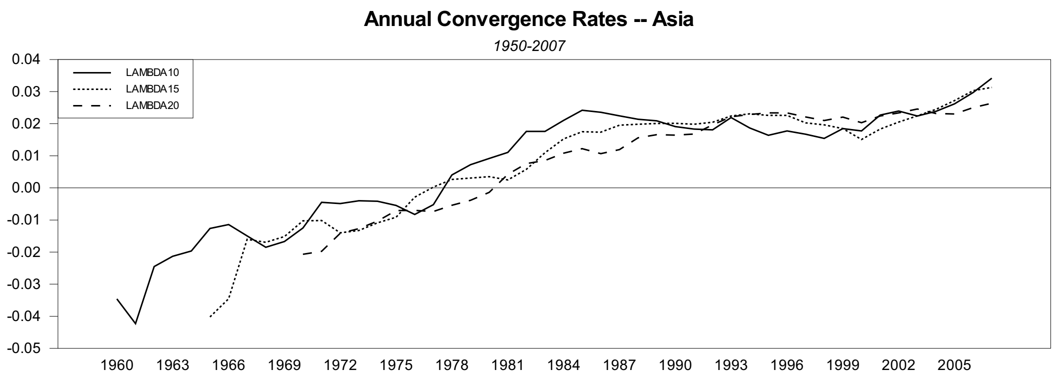

Figure 6: Convergence Rates over time – ASIA

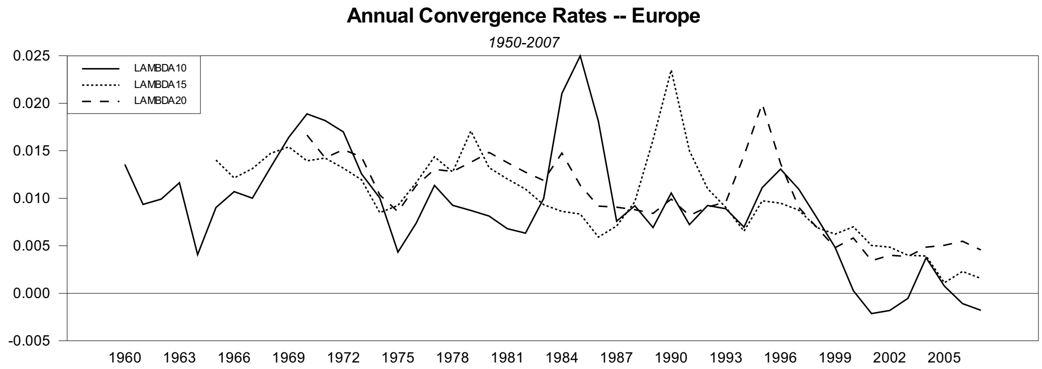

Figure 7: Convergence Rates over time – EUROPE

Appendix

List of Countries and Average Growth Rates

	Growth Rate		Growth Rate
1.Argentina	1.29%	32.Kenya	0.37%
2.Australia	2.27%	33.Luxembourg	3.00%
3.Austria	3.37%	34.Mauritius	2.33%
4.Belgium	2.69%	35.Mexico	2.25%
5.Bolivia	0.28%	36.Morocco	2.25%
6.Brazil	2.78%	37.Netherlands	2.45%
7.Canada	2.21%	38.New Zealand	1.65%
8.Chile	2.48%	39.Nicaragua	0.74%
9.China	5.97%	40.Nigeria	1.75%
10.Colombia	1.82%	41.Norway	2.98%
11.Congo,Dem.Rep.	1.65%	42.Pakistan	2.41%
12.Costa Rica	2.20%	43.Panama	3.01%
13.Cyprus	4.43%	44.Paraguay	1.15%
14.Denmark	2.50%	45.Peru	1.61%
15.Dominican Rep.	3.13%	46.Philippines	2.15%
16.Ecuador	1.86%	47.Portugal	3.74%
17.Egypt	2.74%	48.Puerto Rico	3.76%
18.El Salvador	1.20%	49.South Africa	1.51%
19.Ethiopia	1.16%	50.Spain	3.98%
20.Finland	3.18%	51.Sri Lanka	2.75%
21.France	2.73%	52.Sweden	2.27%
22.Greece	3.56%	53.Switzerland	1.97%
23.Guatemala	1.34%	54.Taiwan	5.98%
24.Guyana	0.84%	55.Thailand	3.73%
25.Honduras	0.81%	56.Trinidad & Tobago	3.66%
26.Iceland	3.03%	57.Turkey	2.86%
27.India	2.80%	58.Uganda	0.65%
28.Ireland	3.65%	59.United Kingdom	2.30%
29.Israel	2.84%	60.United States	2.14%
30.Italy	3.24%	61.Uruguay	1.52%
31.Japan	4.47%	62.Venezuela	1.07%

Notes. Growth rate is the average annual growth rate of GDP per capita, computed over 1951-2007.