A New Approach for Analysing Income Convergence across Countries.[a]

Donal O'Neill[*] and Philippe Van Kerm[**]

January 2004
Preliminary Draft

Abstract

In this paper we develop a coherent framework that integrates both traditional measures of β-convergence and σ-convergence within a study of cross-country income dynamics. To do this we exploit the close links that exist between studies of income convergence and studies analysing the progressivity of the tax system. Our framework offers a simple algebraic decomposition of σ-convergence as the combined effect of β-convergence and leapfrogging among countries. We illustrate our approach using data for the period 1960-2000.

[*] Economics Dept., NUI Maynooth, Maynooth, Co. Kildare,Ireland, donal.oneill@may.ie
[**] CEPS/INSTEAD G.-D Luxembourg, philippe.vankerm@ceps.lu

1. Introduction

The degree to which income or productivity levels have converged across countries, over time, has been the subject of extensive research. Initial studies tended to be descriptive - highlighting the key trends in inequality over time (Abramovitz (1986), Baumol (1986)). However, in recent years this work has become more closely connected with research in economic growth theory. Two theories have come to dominate the literature on economic growth. The traditional Solow growth model (Solow (1956)) predicts that countries that are furthest away from their steady states will grow more quickly than countries closer to their steady state. For countries with the same steady state this implies that incomes will converge along the transition path. In contrast endogenous growth models (Romer (1986)) can generate patterns of growth that do not exhibit any tendency towards convergence.[1] Initially it was suggested that the presence or otherwise of convergence could form the basis of a test of the neo-classical growth model against the more recent endogenous growth models. As a result, several papers were written examining the nature of the convergence process (e.g Barro and Sala-I-Martin (1992), Mankiw, Weil and Romer (1992)). As a consequence of this work however, there has been much controversy, debate and confusion regarding how to measure and interpret income convergence.

The dominant approach in the early literature is characterised by the work of Barro and Sala-i-Martin (1992). This involves regressing income growth rates on initial income to test whether poor countries grow faster than rich countries.[2] However, several authors (Friedman (1992) and Quah (1993)) have argued that these regressions detect mobility within a distribution but tell us little about whether income dispersion across countries has fallen: it is possible to observe poor countries growing faster than rich countries and yet for incomes to diverge. For this to happen it must be the case that the initially poorer countries overtake/leapfrog the richer countries, so

---

[1] The key distinction between these two models is the presence or otherwise of diminishing returns to capital. For a more detailed discussion of alternative growth models and their implications for the evolution of the international distribution of income see de la Fuente (1997).

[2] Essentially one considers a regression model of the form $\log\left(\dfrac{y_{i,t+1}}{y_{i,t}}\right) = \alpha + \beta \log(y_{i,t}) + \varepsilon_{i,t}$.

Values of β<0 are taken as evidence of convergence. In practice a non-linear version of this equation may be estimated but this makes little difference to the final results. It can be easily shown that -β measures how rapidly an economy's output approaches its steady state.

that the rankings of countries are reversed.[3] To distinguish between these different forms of convergence Sala-i-Martin (1996a) coined the term *β-convergence* to capture situations where "*poor economies tend to grow faster than rich ones.*"[4] The term *σ-convergence* is defined as follows: "*a group of economies are converging, in the sense of σ, if the dispersion of their real per capita GDP levels tends to decrease over time.*" While Friedman (1992) has argued that the real test of convergence should focus on the consistent diminution of variance among countries, Sala-i-Martin (1996a,b) argues that both concepts of convergence are interesting and should be analysed empirically.

In this paper we establish the close links that exist between existing measures of *β-convergence* and measures of tax progression used in the public economics literature. We exploit this relationship to develop a framework for studying realised income dynamics. This new approach incorporates the traditional measures of convergence in a coherent way. We measure *σ-convergence* as the change in the Gini coefficient over time and examine its components using the exact additive decomposition suggested by Jenkins and Van Kerm (2003). By analogy to the tax progression and income mobility literature, the two components of the decomposition can be interpreted as the contribution of *β-convergence* and leapfrogging to overall *σ-convergence*. Our framework reveals more about income dynamics than studies based only on regression coefficients or correlation coefficients, yet is less demanding than full-scale estimation of the joint income distribution. Since our approach can also incorporate varying degrees of inequality aversion when measuring dispersion, it allows us to use a family of dispersion measures when studying convergence. This permits a robust analysis of income convergence across a range of variability measures. To illustrate our approach we examine income dynamics across countries from 1960-2000.

2.Decomposing Inequality:
σ-convergence, Progressivity, Reranking, β-convergence and Leapfrogging.

---

[3] Tamura (1992), Brezis et al (1993) and Sugimoto (2003) present examples of growth models in which leapfrogging/overtaking occurs. Tamura (1992) and Sugimoto (2003) emphasise the role of inequality within countries in generating differential growth paths, while Brezis et al (1993) focus on the disadvantage of leading countries in adopting new technologies.

[4] In that paper Sala-i-Martin dates the first use of this term to his Ph.D thesis in 1990.

Previous studies of cross-country income dispersion have tended to use either the coefficient of variation of GDP (e.g Friedman (1992)) or the standard deviation of log GDP (e.g Sala-i-Martin (1996a)) to summarise income inequality. In this paper we focus instead on the Gini coefficient.[5] The Gini coefficient measures twice the area between the 45-degree line and the Lorenz Curve, $L_x(p)$, and has been used extensively in the public economics literature dealing with taxation and income redistribution issues.[6] In this paper we adapt the framework developed in the public economics literature so as to study the dynamics of income inequality across countries. To do this we must first define the concentration curve for Z (with respect to X), which we denote as $CC^x_z(p)$. $CC^x_z(p)$ plots the cumulative shares of Z against quantiles in the X-distribution. It is important to note that $CC^x_z(p)$ will differ from $L_z(p)$ in situations where the rankings of individuals based on X and Z differ. In the same way as the Gini-coefficient is derived from the Lorenz curve, we can also define an area based measure of the extent to which the concentration curve deviates from the 45-degree line. This is known as the *Concentration coefficient C^x_z.*

We can now view any change in inequality as a two-step process. To see this let X_i denote income of country i in period 1 and Y_i denote income in period 2; formally $Y_i=X_i(1+g_i)$, where g_i measures the income growth rate for country i. We define a growth process to be progressive if the growth rate g_i is decreasing with income; regressive if g_i increases with income; and proportional if g_i is constant across income levels.[7] The change in the Gini coefficient over time can be decomposed as follows:

$$\Delta G = G_Y - G_X = (G_Y - C^X_Y) - (G_X - C^X_Y) = R - P$$

The first term uses only the final distribution of income and measures the increase in inequality due to reranking. The second term measures the redistributive impact of progressivity using only the rankings from the initial income distribution. In the tax literature this term is often referred to as the Reynolds-Smolensky index of vertical equity. It is proportional to the Kakwani measure of tax progressivity. It is

---

[5] For a comparison of alternative measures of inequality see Cowell (1995). For studies using Lorenz Curves and Gini coefficients to study regional income convergence in the U.S. see Bishop et al (1992, 1994).

[6] For a detailed discussion of these issues see Lambert (1993).

[7] This terminology differs slightly from that used in the tax-benefit literature (see Lambert (1993) page 250). In that literature benefits are said to be distributed regressively if the benefit rate declines with income. This implies that a regressive benefit system exerts an equalising effect on the income distribution. We prefer to use the term progressive to describe the analogous situation in the growth context.

easily shown that P will equal zero if the growth rate is proportional. P is positive if the growth process is progressive; a factor leading to lower inequality over time. In contrast, P is negative if the growth process is regressive; a factor tending to increase inequality. The more progressive is the growth process, the greater the value of P and hence the larger the reduction in inequality. Viewing the change in inequality in this way allows us to identify the relative contribution of both re-ranking and progressive growth to the overall change in inequality, ΔG. The decomposition can be easily generalised to settings that use the generalised *S-Gini* coefficient ($G_x(v)$).[8] This coefficient allows the researcher to incorporate a parameter of inequality aversion, *v*, when calculating the summary measure of dispersion. Intuitively the S-Gini allows for different weights to be attached to different income ranges when integrating over the Lorenz curve.

The parallel between our presentation of income dynamics and the existing work on income convergence across countries is immediate.[9] *ΔG* denotes the change in income dispersion over time and is therefore a direct measure of *σ-convergence*. The progressivity term, *-P(v),* captures the extent to which income inequality is reduced over time as a result of higher growth rates among lower income countries: it is a measure "pro-poor income growth". Expressed in this way it becomes obvious that *β-convergence,* defined as situation where "*poor economies tend to grow faster than rich ones",* is nothing more than progressive (or "pro-poor") income growth. As a result, the progressivity term in our decomposition measures the contribution of *β-convergence* to the overall reduction in income dispersion. The other term in the decomposition measures the negative impact of positional mobility on income inequality. In the growth context this captures the notion of leapfrogging or reranking.

We can use Figures 1-5 to illustrate our decomposition. These figures give a sample of the range of income dynamics that are easily captured using our framework. Figures 1 and 2 both illustrate situations where *β-convergence* and *σ-convergence* coexist. In the first situation there is no leapfrogging. In our approach the *σ-convergence* would be captured by a fall in the Gini coefficient. For this example all of this reduction would be attributed to the progressivity of income growth, so that *ΔG=-P*. The absence of reranking would be reflected in a measure of *R=0*. In the

---

[8] For a more detailed discussion see Donaldson and Weymark (1980).

second example incomes converge despite rereanking. This would be captured in our framework by values of P and R such that P>0, R>0 and P>R, highlighting the dominant role of pro-poor income growth or *β-convergence* in reducing inequality.

Figures 3 and 4 both illustrate situations where there is no *σ-convergence* *(ΔG=0)*. In the example in Figure 3, however, poor countries grow faster than rich countries so that we have substantial *β-convergence*. This is masked in the overall inequality figure by the complete reranking of the two countries. Our approach will identify the redistributive contribution of *β-convergence* to inequality in these data but this will be entirely offset by the contribution of the leapfrogging component, so that *P=R>0*. Not only does our framework identify the tendency of poor countries to grow faster but it also simultaneously quantifies the extent to which this is offset by reranking in the data. In contrast, Figure 4 illustrates another process for which there is no *σ-convergence*. However, this case differs from that in Figure 3 in that this new process is static. Again *ΔG=0*, but for this process our decomposition would result in *P=R=0*. Our decomposition would identify this as a growth process without either *β-convergence* or *leapfrogging*.

There are theoretical reasons as to why one might wish to distinguish between the examples in Figures 3 and 4. The steady state in a Solow Growth model is characterised by a constant dispersion in income. In a stochastic version of the model this dispersion need not be zero; random shocks may have effects on countries even in the steady state. However, as noted by de la Fuente (1997), "Such disturbances will only have transitory effects, implying that in the long-run we should observe a fluid distribution in which relative positions of the different countries change rapidly (page 36)." Thus the steady state dynamics should correspond to Figure 3 rather than Figure 4. Our framework provides a straightforward way of distinguishing between these processes. Finally, Figure 5 illustrates a situation where we have *β-convergence* and *σ-divergence*. Here the effect of the leapfrogging induced by the pro-poor income growth more than offsets the reduction in inequality arising from *β-convergence*. In this case we have *ΔG >0, P>0, R>0 and R>P*.

These examples also help clarify an important point; Sala-i-Martin (1996b) begins his paper by defining *β-convergence* in the traditional way, noting that "*there*

---

[9] Recent papers by Benabou and Ok (2001) and Jenkins and Van Kerm (2003) use similar concepts to study individual income mobility.

is β-convergence if poor economies tend to grow faster than rich ones." However, later in the paper he suggests that *β-convergence* studies the mobility of income within the same distribution. As a result, some researchers (Boyle and McCarthy (1997)) have drawn parallels between *β-convergence* and measures of rank mobility: defining indices of rank concordance as direct measures of *β-convergence*. Clearly for a distribution to exhibit *β-convergence,* without *σ-convergence,* it must be the case that countries are changing ranks (Figure 3). However, as Figure 1 shows, it is possible to have *β-convergence* without any positional mobility; it is also possible to have rank mobility without *β-convergence*. The definition of *β-convergence* simply requires poor countries to grow faster than rich countries, *irrespective of whether or not there is leapfrogging*. Both a Barro-regression approach and our redistributive approach would indicate a strong role for *β-convergence* for the process illustrated in Figure 1; measures based on rank correlations would not. While the issue of positional mobility is interesting, it is captured by our measure R; this in turn measures *reranking/leapfrogging* and not *progressivity/β-convergence*.

Quah (1996) uses diagrams similar to these to argue that neither *β-convergence* nor *σ-convergence* deliver a convincing description of the dynamics of evolving distributions. Quah (1996) proposes an alternative procedure based on estimation of stochastic Kernels; our analysis builds upon established work in public economics to offer a coherent alternative to Quah's approach. Our framework integrates the three important features of the convergence process: *σ-convergence; β-convergence* and *leapfrogging,* in a way that is easy to implement and interpret. The next section provides an empirical illustration of this approach. We apply our decomposition to data on cross-country income dynamics taken from the latest release of the Penn-World tables.

3: Data and Results

3.1 Data

In this section of the paper we analyse income convergence between 1960 and 2000, using data from the latest version of the Penn-World Tables.[10] The Penn World Tables provide price adjusted income measures for 168 countries for the years 1950-

---

[10] Alan Heston, Robert Summers and Bettina Aten, Penn World Table Version 6.1, Center for International Comparisons at the University of Pennsylvania (CICUP), October 2002.

2000 and have been used extensively in previous studies of convergence. In this paper we use data for a sample of 98 countries that provide complete data over the period 1960-2000. We also look at income dynamics for a restricted set of 25 OECD countries. Income is measured as real per-capita gross domestic product in 1996 international prices. The countries used in our analysis are presented in Tables 1 and 2.

Figures 6 and 7 provide a useful graphical summary of the evolution of income inequality over the period 1962-1998. Figure 6 summarises the data for the OECD sample, while Figure 7 provides the results for the full sample. We focus first on the OECD countries. For the purpose of constructing this graph we used a 5-year moving average of incomes; the income for 1962 is thus an average of that country's income from 1960-1964; likewise income in 1998 is an average of incomes from 1996-2000. Incomes are expressed relative to the overall mean for that year; values above 1 correspond to high-income countries and values below 1 represent low-income countries. The North East (NE) and South West (SW) quadrants of Figure 6 are simple transformations of the empirical distribution functions of incomes in the two periods; they establish a relationship between income and rank in each of the two years. The estimated (non-linear) line in the North West (NW) quadrant maps the relationship between incomes in these two marginal distributions. The y-coordinate of this line shows the income a country would have expected to receive in 1998, predicted using their initial 1962 income. The 45-degree line corresponds to a situation of proportional income growth. More formally we can show that our progressivity measure, P, is a weighted integral of the individual differences of each country point to the 45-degree line (Jenkins and Van Kerm 2003). The graph shows that countries with low initial incomes would have expected their income to rise fastest over this period. This is a simple graphical presentation of the tendency towards *β-convergence* that occurred for the OECD countries over this time period.

The South East (SE) captures the extent of *leapfrogging*. Deviations from the 45-degree line in this quadrant show the extent of re-ranking; countries above the 45-degree have increased their rank over time and vice versa. The results show that almost every country changed rank over this period; countries such as Ireland, Japan and Norway moved up the distribution; countries such as Sweden, New Zealand and Britain moved down. There is no immediate mapping from this graphical presentation

of leapfrogging to our summary measure R; the easiest way to visualise the impact of leapfrogging on relative incomes is to look at the nature and composition of income clusters in both years. Looking at the NW quadrant for 1962 (along the horizontal axis) we can identify approximately 3 clusters of countries: a low-income cluster consisting of Korea, Turkey, Mexico, Greece, Portugal, Spain, Japan and Ireland; a high-income cluster involving Luxembourg, USA and Switzerland; and a cluster of middle-income countries made up of the remaining OECD members. Switching axis to look at 1998, there still appears to be a low income, middle-income and high-income cluster; furthermore, our graph allows us to look at compositional changes within and between these clusters. We notice that Switzerland has fallen out of the high-income group into the middle-group; New Zealand, which was initially at the upper end of the middle-income group, is now at the lower end of this group; the big movers out of the low-income group were Ireland and Japan, who have now joined the middle-income countries.

Figure 7 provides the same analysis for the full sample of 98 countries. The growth in relative incomes for this sample tends to be concentrated in the middle of the distribution, with relative incomes at the very top of the distribution falling Although identifying individual countries becomes more difficult, it is apparent that much of the leapfrogging that occurred over this time period resulted in countries changing positions within groups; relatively few countries changed groups. In the next section we use the decomposition presented earlier to look at these changes more formally.

3.2 σ-convergence, β-convergence and *leapfrogging 1960-2000.*

The results of our analysis are presented in Tables 3-6. Tables 3 and 5 refer to the OECD sample, while Tables 4 and 6 refer to the full sample. Table 3 reports the Generalised Gini coefficient for the set of OECD countries, at 10-year intervals, for the period 1960-2000. We report the Gini for three values of the inequality aversion parameter equal to 1.5, 2, 2.5, respectively; the first places relatively more weight on incomes at the top of the distribution; the second corresponds to the regular Gini-coefficient; the third gives relatively more weight to inequality at the low end of the distribution. For completeness we also report the standard deviation of log income. The overall trend is similar for all four measures and indicates a substantial reduction

of income dispersion over the period 1960-2000. For each measure the majority of this reduction took place between 1960 and 1980; convergence slowed down significantly after this period.[11] How we interpret the trend in the last 20 years depends on the relative weight given to inequality at the top end of the distribution; when we place more weight on income differences at the top end of the distribution we find that inequality increased substantially in the last 10 years; in fact according to this measure inequality in 2000 is higher than it was in 1980.[12] In contrast, when we place more weight on inequality at the low end of the distribution we find that, despite a slowdown in convergence, inequality continued to decline in recent years. These contrasting results suggest that the slowdown in income convergence over this period is driven by a small number of the richest countries pulling away from the rest of the distribution; as a result the income share of the wealthiest countries has increased substantially. All the measures used in Table 4 confirm what has been established in many previous studies; for the world as a whole, incomes diverged substantially over this period.

The results in Tables 5 and 6 decompose these changes in income inequality using the framework outlined in section 2. This approach allows us to determine the redistributive impact of income growth for both samples. The results are provided for the traditional Gini coefficient. The rows of the tables refer to different time periods, while the columns refer to the various components of the convergence process; the first column shows the change in the Gini coefficient and measures σ-*convergence*; the second and third columns present the respective contributions of progressive income growth *(β-convergence)* and reranking (leapfrogging) to the change in overall inequality.[13] The final column reports the traditional measure of β-*convergence* derived from a Barro-regression.

---

[11] This slowdown in convergence among developed countries was discussed in O'Neill (1996). The analysis in that paper suggests that the slowdown may be related to changes in the rate of human capital accumulation.

[12] This is not evident in Figure 6, which plots the evolution of income inequality over the entire 40 years. However if we repeat the analysis for the same sub-periods as reported in Table 1, the same trend of rising relative income at the very top of the distribution between 1978-88 and 1988-1998 becomes apparent. In the interests of brevity we have omitted the graphical summary for each of the sub-periods, though these are available from the authors upon request.

[13] The standard errors on the decomposition terms were constructed using a bootstrap procedure with 1000 replications. These estimates are similar in magnitude to the approximate analytic standard errors constructed using Jean-Yves Duclos's DAD software http://www.ecn.ulaval.ca/~jyves/index.html.

Looking at the results in Table 5 we see that leapfrogging plays only a minor role in the cross-country income dynamics of OECD countries; re-ranking did very little to offset the reduction in inequality induced by *β-convergence* between 1960 and 1980.[14] Furthermore, we see that the stable income distribution observed over the last 10 years reflects a static distribution; neither *leapfrogging* nor *β-convergence* contribute anything to changes in income dispersion across countries over this period. The last column presents our estimates of the traditional measure of *β-convergence* from growth regressions; the results are reported so that a negative *β* indicates convergence. For the most part these results are consistent with our earlier analysis; the early periods are characterised by significant *β-convergence;* this is absent in the later years. However, it is worthwhile making two observations: Firstly, in every period under consideration we observe both leapfrogging and values of $|\beta|<1$; therefore, we need to be careful when interpreting claims that $|\beta|<1$ rules out leapfrogging; this applies only to "deterministic" leapfrogging, where poor economies are *systematically* predicted to get ahead of rich economies; a value of $|\beta|<1$ says nothing about positional mobility in general. In theory it is possible to extend our decomposition to distinguish between systematic leapfrogging and stochastic leapfrogging using the procedures outlined by Duclos et al (2003); however this requires a reliable estimate of the growth schedule. Given the small number of observations in our samples this is likely to prove difficult. As a result we did not attempt to distinguish between different sources of re-ranking in our analysis. Secondly, it is interesting to compare the full period from 1960-2000, with that from 1980-1990; for both these periods the estimated *β* coefficient from the growth equations are almost identical. However, when you look at columns 2 and 3 we see that, for the two periods in question, the dynamics underlying the income distribution were substantially different. For the overall period progressive income growth had a significant redistributive effect; as a result income inequality declined substantially. In the later period, however, total income inequality did not change. Furthermore our decomposition shows that neither leapfrogging nor *β-convergence* was important over this period; as a result effective *β-convergence* fell substantially over this period.

---

[14] Using measures of rank correlations Boyle and McCarthy (1997) also concluded that "positional mobility" was relatively unimportant over this time. However, our approach differs in two ways; firstly we can determine precisely the contribution of this component to income dynamics; secondly we do not equate positional mobility with β-convergence.

Relying on Barro-regressions to identify *β-convergence* would miss these differences. Dardanoni and Lambert (2002) make a similar point in a different context; they note that tax schedules with similar measures of structural progression can differ substantially in their effective redistribution. Therefore, even if we accept the seemingly well-established tendency for Barro-regressions to return a rate of convergence of 2% over a wide range of different examples, our framework shows how the redistributive effects of these processes may differ substantially.[15]

Table 5 presents the results for the world as a whole. In contrast to the OECD sample we find little evidence of *β-convergence;* for almost every period considered the regressive nature of income growth and any observed leapfrogging combined to increase income dispersion. When the full 40-year period is considered we see that leapfrogging was the dominant force driving income dynamics; this at a time when the redistributive effect of growth was regressive. Again the results are, for the most part, consistent with the traditional Barro-regression; however, again we see the potential for processes with similar coefficients from the Barro-regression (1970-80 and 1980-1990) may be associated with somewhat different levels of effective redistribution.

3.3 Conditional β-Convergence

Following Mankiw, Weil and Romer (1992) and Barro and Sala-I-Martin (1995) we can adapt our framework to deal with distinctions between *absolute β-convergence* and *conditional β-convergence*. The analysis presented earlier focused on whether or not poor countries grew faster than richer countries; this concept has been labelled as *absolute β-convergence* in the growth literature. However, it is well known that models such as the Solow growth model do not necessarily predict *absolute β-convergence*; instead, it predicts that countries that are further away from their steady states will grow faster than countries closer to their steady state. In the event that all countries share the same steady state this will manifest itself in poorer countries growing more quickly; however, if we allow countries to have different steady states this is no longer the case; instead, we must modify our approach to consider *conditional β-convergence*: conditional convergence examines the

---

[15] See Quah (1996) for a critical analysis of the uniformity of convergence rates across different samples and time-frames.

relationship between growth and initial income after controlling for differences in steady state incomes.

The traditional test for *conditional β-convergence* involves regressing growth on initial income, holding constant a number of additional variables that determine steady state income; if the partial correlation between growth and income is negative we say that the data exhibit *conditional β-convergence*. Such a distinction may not be important among groups of countries that are relatively homogenous, such as those members of the OECD. However, a number of researchers have shown that this distinction can be important when looking at more heterogeneous sets of countries. With this in mind we modify our approach so as to examine the importance of *conditional β-convergence* for the full sample of countries in our study. To partial-out differences in steady state incomes across countries we run the following regression for each year in the sample:

$$RGDP_i = \alpha + \delta_1 S_{Ki} + \delta_2 n_i + \varepsilon_i$$

where $RGDP_i$ is real GDP per capita for country I; S_{Ki} is the average share of real investment in real GDP for country i over full sample period; and n_i is the average rate of growth of the working age population for country i. The savings rate and the population growth rate are key determinants of steady state incomes in exogenous growth models; using the residuals from the above regression as a measure of income should eliminate much of the heterogeneity arising from differences in steady state incomes.[16] Having obtained the residuals for each country and each year, we rescale the annual residuals so as to have the same mean as the raw GDP series for that year[17]; these rescaled residuals are then used to examine income convergence using the framework outlined in section 2. The results are presented in Table 7; the

---

[16] Mankiw, Weil and Romer (1992) use a similar approach in their regression analysis of conditional convergence.

[17] It is necessary to rescale the residuals before applying our framework since the raw residuals have a mean zero; as a result the Gini coefficient is not defined for the raw residual series. Formally the Gini coefficient can be written as $G = \dfrac{\sum_i \sum_j |y_i - y_j|}{N^2 \mu}$. Rescaling the residuals, as we have, ensures that the differences between the estimated Gini for the raw and residualised GDP series reflects only differences in the average absolute deviations of both series. This seems a reasonable way to proceed.

contribution of the re-ranking component (column 4) does not change much when we move from absolute to conditional convergence; however, in keeping with earlier work, we now find evidence of substantial *conditional β-convergence;* this is true with either the traditional Barro measure of convergence or our measure of effective convergence; the latter focuses directly on the redistributive impact of progressive income growth. Although, there is some evidence that leapfrogging partly offset the effect of *β-convergence* on overall income dispersion, especially when we take a 40 year horizon, the net effect is still largely determined by the level of *β-convergence.*

4. *Conclusion*

The results presented in this paper are consistent with earlier studies that have examined inequality across countries. However, we believe that the approach adopted in our paper represents a significant development in the analysis of cross-country income dynamics; the techniques we use allow us to "marry" the approaches advocated by Friedman and Quah, with those suggested by Barro and Sala-I-Martin. In doing so we develop a coherent integrated framework involving concepts that, up to now, have often been viewed as competitors in the analysis of income dynamics. To do this we adapt concepts originally developed to study the progressivity of the tax system and apply them to study cross-country income dynamics; doing so provides a simple integrated framework for studying income dynamics. This framework allows us to easily evaluate and understand the connections between the various sources of convergence discussed in the literature. Our results suggest that, for almost all of the samples and time-periods where *β-convergence* occurred, the presence of leapfrogging did little to offset the reduction in overall dispersion induced by *β-convergence*; when both processes occurred the net effect was largely determined by the level of *β-convergence.*

However we note that different rescaling constants will led to different values for both the residualised Gini and the estimated components of the decomposition.

References

Abramovitz, M (1986), "Catching Up, Forging Ahead and Falling Behind," *Journal of Economic History,* 46, June, pp. 385-406.

Atkinson, A (1970), "On the Measurement of Inequality," *Journal of Economic Theory,* Vol. 2, pp. 244-263.

Barro, R and X. Sala-Martin (1992), "Convergence," *Journal of Political Economy,* 100, 2 (April), 223-251.

Barro, R and X. Sala-Martin (1995), Economic Growth, McGraw-Hill, New York.

Baumol, W (1986), "Productivity Growth, Convergence and Welfare: What the Long-Run Data Show," *American Economic Review*, 76, December, pp. 1072-85.

Benabou, R and E. Ok (2001), "Mobility as Progressivity: Ranking Income Processes According to Equality of Opportunity," *NBER* Working paper 8431.

Bishop, J, J. Formby and P. Thistle (1992), "Convergence of the South and Non-South Income Distributions, 1969-1979," *American Economic Review,* March, pp. 262-272.

Bishop, J, J. Formby and P. Thistle (1994), "Convergence and Divergence of Regional Income Distributions and Welfare," *Review of Economics and Statistics,* pp. 228-235.

Boyle, G and T.McCarthy (1997), "A Simple Measure of β-Convergence," *Oxford Bulletin of Economics and Statistics,* Vol. 59, No. 2, pp. 257-264.

Brezis, E, P. Krugman and D. Tsiddon (1993), "Leapfrogging in International Competition: A theory of Cycles in National Technological Leadership," *American Economic Review,* Vol 83 (5) pp. 1211-1299.

Cowell, F (1995), "Measuring Inequality, LSE Handbook in Economics Series, Prentice Hall.

Dardanoni, V and P.Lambert (2002), "Progressivity Comparisons," *Journal of Public Economics*, Vol. 86, pp. 99-122.

de la Fuente, A (1997), "The Empirics of Growth and Convergence: A Selective Review," *Journal of Economic Dynamics and Control*, Vol. 21, pp. 23-73.

Donaldson, D and J. Weymark (1980), "A Single-Parameter Gerneralization of the Gini Indices of Inequality," *Journal of Economic Theory,* 22, pp. 67-86.

Duclos, J-Y, V. Jalbert and A. Araar (2003), "Classical Horizontal Inequity and Reranking: an Integrating Approach," CIRPEE Working paper 03-06.

Friedman, M (1992), "Do Old Fallacies Ever Die?," *Journal of Economic Literature,* Vol. XXX, no. 4, pp. 2129-2132.

Jenkins, S and P. Van Kerm (2003), "Trends in Income Inequality, Pro-Poor Income Growth and Income Mobility," IRISS Working paper no. 2003-11, CEPS/INSTEAD, Differdange, G.-D. Luxembourg.

Kakwani, N (1977), "Measurement of Tax Progressivity: An International Comparison," *The Economic Journal*, Vol. 87, pp. 71-80.

Lambert, P (1993) The Distribution and Redistribution of Income, Manchester University Press, Manchester, U.K..

Mankiw, G, D. Weil and P. Romer (1992), "A Contribution to the Empirics of Growth," *Quarterly Journal of Economics*, Vol. 107, pp. 407-37.

O'Neill, D (1996), "Education and Income Growth: Implications for Cross-Country Inequality," *Journal of Political Economy*, Vol. 103, no. 6, pp. 1289-1301.

Quah, D (1993), "Galton's Fallacy and tests of the Convergence Hypothesis," *The Scandanavian Journal of Economics,* 95, pp. 427-443.

Quah, D (1996), "Empirics for Economic Growth and Convergence," *European Economic Review,* June.

Romer, P. (1986) "Increasing Returns and Long-Run Growth," *Journal of Political Economy,* 99, June pp. 500-21.

Sala-I-Martin, X (1996a) "The Classical Approach to Convergence Analysis," *Economic Journal*, Vol. 106, pp. 1019-1036.

Sala-I-Martin, X (1996b) "Regional cohesion: Evidence and theories of Regional Growth and Convergence," *European Economic Review,* Vol. 40, pp. 1325-1352.

Shorrocks, A (1983) "Ranking Income Distributions," *Economica*, Vol. 50, pp. 1-17.

Solow, R. (1956) "A Contribution to the Theory of Economic Growth," *Quarterly Journal of Economics*, 70, February, pp. 65-94.

Sugimoto, Y. (2003), " Inequality, Growth and Overtaking," Dept. of Economics, Brown University.

Tamura, R (1992), "Efficient Equilibrium Convergence: Heterogeneity and Growth," *Journal of Economic Theory*, Vol. 58, no. 2, pp. 355-376.

Table 1: Full Sample of 98 countries included in the analysis

Argentina	Costa Rica	India	Malawi	Sweden
Australia	Denmark	Ireland	Malaysia	Switzerland
Austria	Dominican Republic	Iran	Niger	Seychelles
Burundi	Algeria	Iceland	Nigeria	Syria
Belgium	Ecuador	Israel	Nicaragua	Chad
Benin	Egypt	Italy	Netherlands	Togo
Burkina Faso	Ethiopia	Jamaica	Norway	Thailand
Bangladesh	Finland	Jordan	Nepal	Trinidad and Tobago
Bolivia	France	Japan	New Zealand	Turkey
Brazil	Gabon	Kenya	Pakistan	Tanzania
Barbados	Ghana	Korea	Panama	United Kingdom
Canada	Guinea	Sri Lanka	Peru	Uganda
Chile	Gambia	Lesotho	Philippines	Uruguay
China	Guinea-Bissau	Luxembourg	Portugal	United States of America
Cote d'Ivoire	Equatorial Guinea	Morocco	Paraguay	Venezuela
Cameroon	Greece	Madagascar	Romania	South Africa
Congo, Republic of	Guatemala	Mexico	Rwanda	Zambia
Colombia	Hong Kong	Mali	Senegal	Zimbabwe
Comoros	Honduras	Mozambique	Spain	
Cape Verde	Indonesia	Mauritius	El Salvador	

Table 2: OECD Countries included in the analysis[*]

Australia	Finland	Italy	Netherlands	Sweden
Austria	France	Japan	Norway	Switzerland
Belgium	Greece	Korea	New Zealand	Turkey
Canada	Ireland	Luxembourg	Portugal	United Kingdom
Denmark	Iceland	Mexico	Spain	United States

[*] Of the 30 countries currently listed as members of the OECD, the Czech Republic, Slovakia, Poland, Hungary and Germany did not have consistent data for the period 1960-2000.

Table 3: Relative Trends in Income Inequality for the OECD countries with alternative degrees of Inequality Aversion

Time Period	$G(1.5)$	$G(2)$	$G(2.5)$	$\sigma_{ln(GDP)}$
1960	.163	.253	.318	.547
1970	.132	.205	.260	.472
1980	.108	.174	.226	.418
1990	.105	.169	.218	.385
2000	.114	.171	.214	.385

Table 4: Relative Trends in Income Inequality for the Full-Sample (N=98) with alternative degrees of Inequality Aversion

Time Period	$G(1.5)$	$G(2)$	$G(2.5)$	$\sigma_{ln(GDP)}$
1960	.327	.483	.572	.928
1970	.337	.503	.600	1.02
1980	.336	.510	.612	1.08
1990	.358	.538	.641	1.14
2000	.370	.553	.659	1.22

Table 5: Income Convergence Dynamics for 25 OECD Countries: 1960-2000.
(Standard Errors in parentheses)

Time period	σ-Convergence ΔG(2)	β-convergence DP(2)	Reranking R(2)	β Barro-Regression
1960-2000	.171-.253 = -.083** (.034)	-.116** (.035)	.033** (.011)	-.012** (.0025)
1960-1970	.205-.253 = -.048 (.013)	-.056 (.015)	.008** (.004)	-.016** (.005)
1970-1980	.174-.205 = -.031** (.010)	-.045** (.010)	.014** (.007)	-.013** (.004)
1980-1990	.169-.174 = -.005 (.014)	-.013 (.013)	.008** (.004)	-.012** (.006)
1990-2000	.171-.169= .002 (.019)	-.009 (.022)	.011** (.006)	-.005 (.006)

** Denotes that the estimate is significantly different from zero at the 5% significance level.

Table 6: Income Convergence Dynamics for the full sample of 98 countries: 1960-2000. (Standard Errors in parentheses)

Time period	σ-Convergence ΔG(2)	β-convergence DP(2)	Reranking R(2)	β Barro-Regression
1960-2000	.553-.483 = .07** (.020)	.017 (.020)	.053** (.013)	.004** (.0015)
1960-1970	.503-.483 = .02** (.008)	.012 (.008)	.008** (.002)	.006** (.002)
1970-1980	.510-.503 = .007 (.008)	-.003 (.008)	.01** (.002)	.003 (.002)
1980-1990	.538-.510 = .028** (.007)	.02** (.007)	.008** (.002)	.003 (.002)
1990-2000	.553-.538= .015 (.008)	.01 (.008)	.005** (.001)	.007** (.002)

** Denotes that the estimate is significantly different from zero at the 5% significance level.

Table 7: Conditional Income Convergence Dynamics for the full sample of 98 countries: 1960-2000. (Standard Errors in parentheses)

Time period	σ-Convergence ΔG(2)	β-convergence DP(2)	Reranking R(2)	β Barro-Regression (s-errors in brackets)
1960-2000	.345-.386 = -.041 (.026)	-.113** (.032)	.072** (.021)	-.005** (.0016)
1960-1970	.362-.386 = -.024** (.012)	-.039** (.015)	.014** (.005)	-.002 (.003)
1970-1980	.339-.362 = -.023** (.011)	-.037** (.011)	.015** (.004)	-.005** (.0028)
1980-1990	.345-.339 = .005 (.012)	-.01 (.010)	.015** (.005)	-.008** (.002)
1990-2000	.345-.345= 0 (.012)	-.011 (.012)	.011** (.005)	.0027 (.003)

** Denotes that the estimate is significantly different from zero at the 5% significance level.

Figure 1:
β-convergence, σ-convergence, no leapfrogging
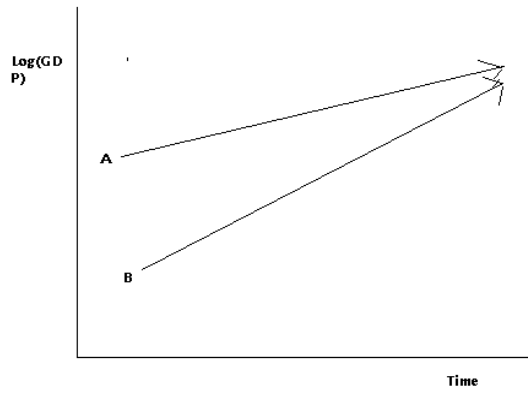
Figure 2:
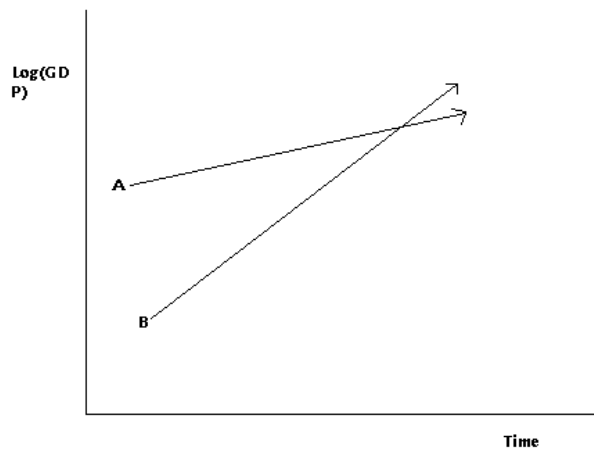*β-convergence, σ-convergence and leapfrogging*

Figure 3:
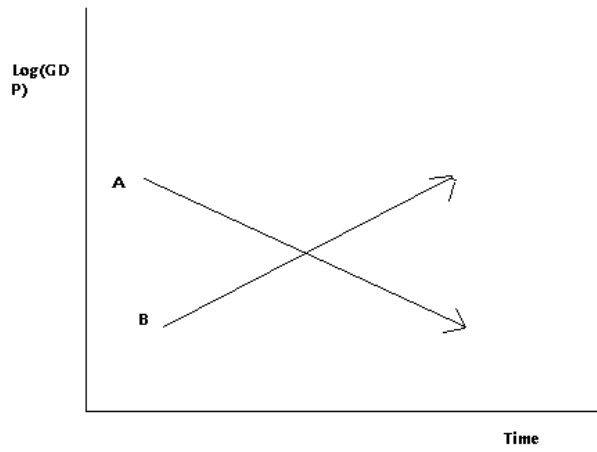*β-convergence, No σ-convergence, Leapfrogging*

Figure4
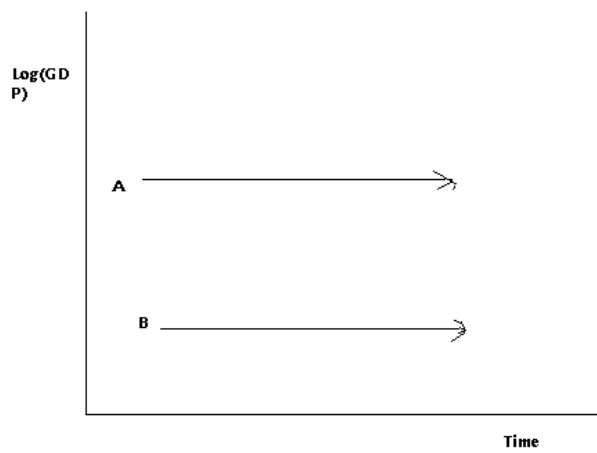*No β-convergence, No σ-convergence, No Leapfrogging*
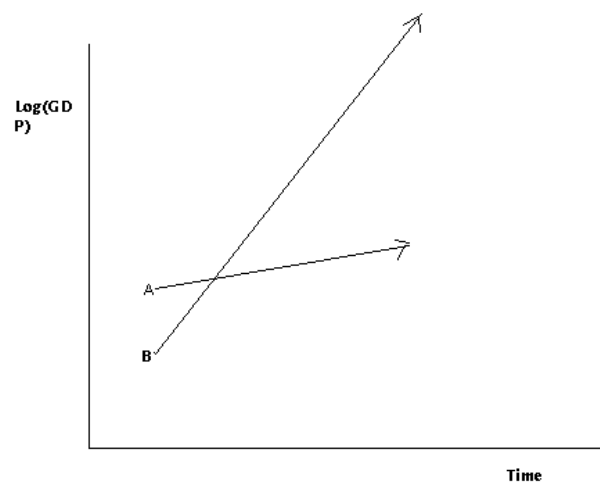
Figure 5
β-convergence, σ-divergence, Leapfrogging

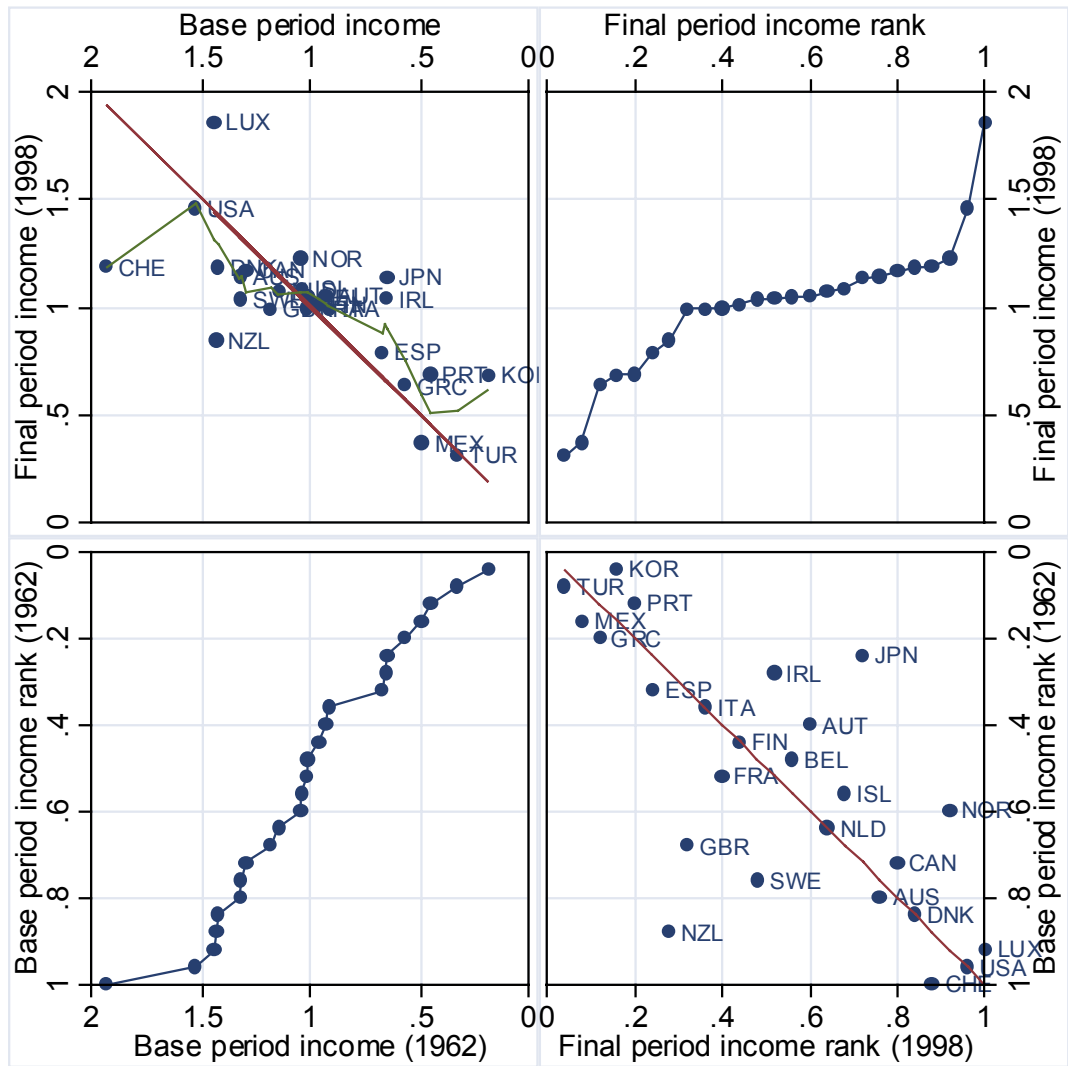Figure 6:Graphical Summary of the Evolution of Income Inequality among OECD countries 1962-1998.

Figure 7: Graphical Summary of the Evolution of Income Inequality among All countries 1962-1998.