Does convergence of incomes still exist among developed economies?
Time series evidence in G7 countries

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Abstract. *In this paper, we examine the presence of convergence of real per capita incomes in G7 countries for the period of 1870-2008, using the group average and pairwise approach. Lee and Strazicich (2003, 2004) unit root tests that provide for structural break(s) are utilised to verify incidence of stochastic convergence, a necessary condition for conditional convergence, while Carlino and Mills (1993) method is employed to confirm the existence of β-convergence, a sufficient requirement for conditional convergence. Among the possible 21 pairwise stochastic convergence cases, we observe nine pairwise stochastic convergence cases, with Japan as the only country not to have stochastic convergence with any of the G7 countries. Although Germany, France and the US stochastically converge towards the G7 average, only the US conditionally converges to the average of G7 countries.*

Keywords: unit root tests; structural breaks; convergence; G7 countries.

1. Introduction

One of the main importations of exogenous growth theory is convergence of cross-national outputs. In a framework of diminishing marginal returns, neoclassical model projects the difference in per capita income of countries to disappear overtime such that initially low income countries will grow more rapidly to catch up with initially high income countries. Economies with similar attributes such as population growth, depreciation rate, savings rate and technology are assumed to converge to the steady-state, which is referred to as absolute convergence. Heterogeneity in attributes of countries is accommodated in Solow model, which argues that economies with varied characteristics will simply converge to their respective steady states. Called conditional convergence, this assumption is less restrictive in comparison to absolute convergence. These propositions have been disputed by endogenous growth theory which suggests divergence of national outputs in a world of constant marginal productivity of capital (at the aggregate level) and dissimilar attributes (Romer, 1990, Aghion, Howitt, 1992).

The two opposing views on convergence spurred empirical scholarships, especially on developed countries. The initial set of empirical literatures such as Baumol (1986), Dowrick and Nguyen (1989) and Sala-i-Martin (1996) apply cross-sectional techniques of comparing countries growth rates of income with their respective initial incomes. Cross sectional techniques usage in assessing income convergence was challenged by Friedman (1992), and Quah (1993). Subsequently, some authors venture into the utilisation of time series in researching convergence of incomes. Common among these new set of literatures is the adoption of OECD (Organisation for Economic Co-operation and Development) countries as representative of developed countries to show convergence is more present in developed countries relative to developing countries (Greasly, Oxley, 1997, Li, Papell, 1999, Strazicich et al., 2004). However, OECD consists of emerging countries such as Mexico, Chile and Turkey that cannot be considered to be fully industrialized. On the other hand, economic blocs such as G7 are purely industrialized countries club. Most of the past literatures on the "OECD countries" are also noticed not to extend beyond 1994[1]. As shown in Table 1 (in which the trend of growth rate income in G7 is separated between the periods of 1871-1994 and 1995-2008), trajectory of growth rate of per capital income has changed drastically. Generally, it is illustrated that most of the growth rate of per capital income of G7 countries has nosedived. For example, Japan experienced 2.969% growth rate in the period 1871-1994 to catch-up with most G7 countries.

However, it only recorded 1.091% for the period 1995-2008. With the exception of UK, all other countries also suffer varying degrees of crash in the growth rate of their incomes between these periods. The slump of the US is lowest at 2.026% in 1871-1994 and 1.809% in 1995-2008. We also observe that previous studies concentrate on multivariate procedures, in which a common benchmark is utilized to test for convergence for all individual countries involved. The results generated are usually generalized to individual income pairs, though heterogeneity in pairwise convergence(s) is ignored. Moreover, most time series consider merely stochastic convergence, but Carlino and Mills (1993) has shown that this is merely a necessary condition for conditional convergence as assumed in the neoclassical model and a further test is needed to verify sufficient condition for conditional convergence.

In this study, we explore the existence of convergence in G7 countries for the 1870-2008 period using Lee and Strazicich (2003) unit root tests. In addition to using the mean of G7 income as benchmark in a multivariate system, we also investigate convergence in a pairwise (bivariate) system, in which the income of one country is compared to the other. Unlike most of the previous researches on convergence of income, we further examine β-convergence, which has been argued by Carlino and Mills (1993) as being required to fulfil the sufficient condition of conditional convergence. Among the contributions of the study is the use of the longest time series so far in the convergence literature as longer time series usually convey better information (Cheung, Pascual, 2004). The rest of this paper is organised as follows. Section 2 briefly reviews the methodology employed in the study. Empirical findings are discussed in Section 3 and finally, Section 4 presents the conclusion of the study.

Table 1. *Growth rate of G7 incomes, 1871-2008*

Period	Countries						
1871-1994	Canada	France	Germany	Italy	Japan	UK	US
Mean	2.107	2.090	2.155	2.137	2.969	1.409	2.026
Median	2.867	2.277	2.624	2.531	3.080	1.750	1.990
Maximum	16.239	49.824	18.234	30.194	17.603	9.479	18.712
Minimum	-16.774	-19.584	-50.893	-21.971	-49.374	-10.787	-21.455
Std. Dev.	5.335	7.342	7.466	5.861	6.875	2.994	5.630
1995-2008	Canada	France	Germany	Italy	Japan	UK	US
Mean	2.096	1.518	1.445	1.246	1.091	2.360	1.809
Median	2.241	1.726	1.415	1.336	1.682	2.478	1.924
Maximum	4.613	3.381	3.211	3.378	3.185	4.286	3.300
Minimum	-2.100	-0.289	-0.276	-0.996	-3.165	0.423	-0.573
Std. Dev.	1.752	0.967	1.042	1.137	1.698	0.897	1.229

Source: http://www.ggdc.net/maddison/Maddison.

1. Methodology

We employ the relative real per capita income to assess stochastic convergence and β-convergence of G7 countries, which are Canada, France, Germany, Italy, Japan, United Kingdom (UK), and the United States of America (US)[2]. The data, which are in annual form for 1870-2008, was extracted from Angus Maddison's homepage at http://www.ggdc.net/maddison/Maddison. In order to check for conditional convergence, we apply the procedure introduced by Carlino and Mills (1993) procedures, which consists of two stages. The first stage deals with the verification of stochastic convergence by using the income of a country relative to average income of all G7 countries, such that:

$$y_{it} = \ln \left[GDP_{it} / \left(\sum_{i=1}^{I} GDP_{it} / I \right) \right] \qquad (1)$$

Here the relative income y_{it} is defined as the ratio of per capita real GDP of country i to the group average. I is the number of countries in the sample. Unit root is performed on the resulting relative income − y_{it} to determine if stochastic convergence exists. This idea is applicable in bivariate case by simply replacing the term of G7 average income with the income of a second country (Bernard, Durlauf, 1996). The study uses this second method for bivariate stochastic test. In either case, failure to reject null hypothesis of unit root demonstrate the case in favour of stochastic convergence. Nevertheless, rejecting null hypothesis of a unit root is a necessary but not a sufficient condition to guarantee conditional convergence, which is met when stochastic convergence and β-convergence exist (Galvao, Reis Gomes, 2007). The second stage involves the verification of β-convergence, which is satisfied if the countries with initial lower income grow faster than those with initial incomes

$$y_{it} = \tau_i + \beta_i t + \varepsilon_{it} \qquad (2)$$

Here ε_{it} is an error term that satisfies the classical assumptions i.e. zero mean and constant variance. For β-convergence to occur, the growth rate(s) of y_{it} must be negative (positive) if the initial value(s) of y_{it} is positive (negative). In other words, τ_i and β_i must produce dissimilar signs. To examine stochastic convergence, time-series offer several unit root tests, which include Augmented Dickey Fuller (ADF) test that does not allow for structural breaks. However, a cursory look at Figure 1, which contains the trajectory of logarithm of per capita income of each country relative to the mean of G7 countries, reveals the presence of structural breaks. Further investigations show that most of these structural breaks are within the vicinity of the Second World War of 1937-1949. Therefore, ignoring structural breaks in the estimations may generate misleading results. There are unit root tests which provide for structural breaks. With the exception of

Lee and Strazicich (2003, 2004) tests, many of these tests are characterised by several deficiencies (Lee, Strazicich, 2001), Lee, Strazicich (2003, 2004) introduced a method of unit root with an endogenous structural break which is unaffected by breaks under the null.

$$\Delta y_t = \delta' \Delta Z_t + \phi \overline{S}_{t-1} + \sum_{i=1}^{p} \chi \Delta \overline{S}_{t-i} + \mu_t \qquad (3)$$

Here Δ represent the first difference operator. $\overline{S}$ denotes a de-trended variable such that $\overline{S}_t = y_t - \hat{\psi}_x - Z_t \hat{\delta}, t = 2...,T$. $\hat{\delta}$ depicts a vector of the coefficients in the equation of Δy_t on ΔZ_t, and $\hat{\psi}_x = y_t - Z_t \hat{\delta}$, with y_1 and Z_1 representing the first observations of y_t and Z_t, respectively. μ_t is the error term, Considering two-time changes in level and trend, $Z_t = \left[1, t, D_{1t}, D_{2t}, DT_{1t}, DT_{2t} \right]'$ where $D_{jt} = 1$ if $t \geq T_{Bj} + 1, j = 1, 2$, and 0 otherwise, and also $DT_{jt} = t$ if $t \geq T_{Bj} + 1, j = 1, 2$, and 0, otherwise. The locations of T_{Bj} which are break dates, are given by $\lambda_j = T_{Bj} / T, j = 1, 2$. Generally, $LM_\tau = \text{Inf}_\lambda \tilde{\tau}(\lambda)$ is used in searching for the break dates, which minimises τ (*t-statistics*) for the null hypothesis of unit root ($\phi = 0$). Augmented terms of $\Delta \overline{S}_{t-1}, i = 1, \ldots k$ are included to circumvent the problem of serial correlation in errors (Lee, Strazicich, 2003, 2004).
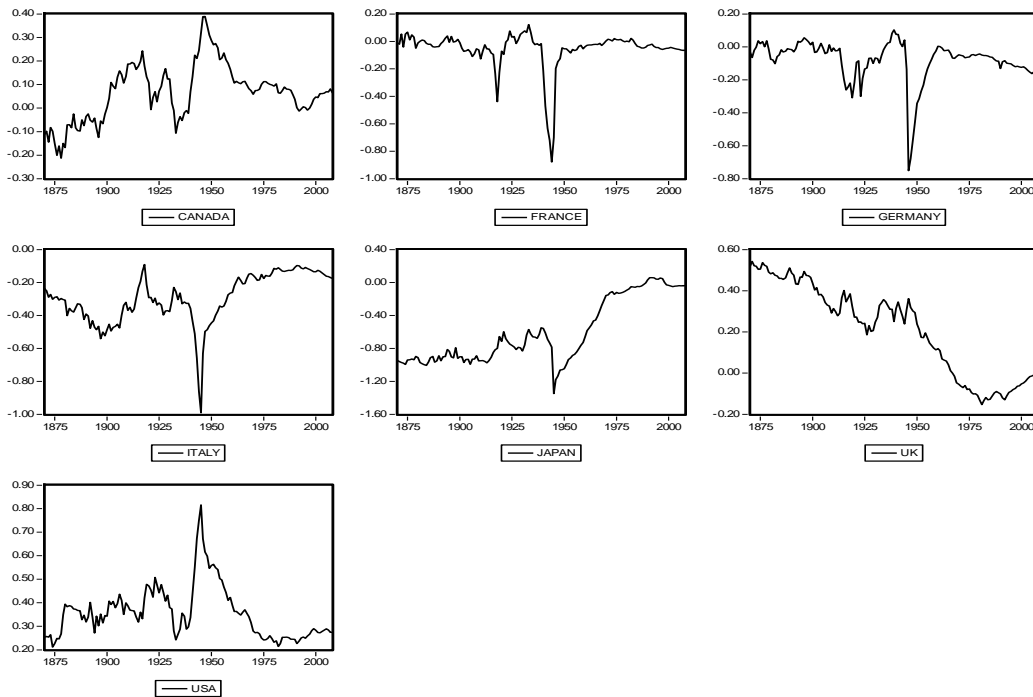

Figure 1. *Per capita income relative to the G7 average, 1870–2008*

Based on the dummies of structural breaks, β-convergence specification needs to be re-specified as $y_t = \zeta_0 + \zeta_1 t + \zeta_2 D_{1t} + \zeta_3 D_{2t} + \zeta_4 T_{1t} + \zeta_5 T_{2t} + \varepsilon_t$ where $\tau = \zeta_0 + \zeta_2 + \zeta_3$, $\beta = \zeta_1 + \zeta_4 + \zeta_5$ depending on the presence of structural breaks. This is applied on relative incomes of countries which display stochastic convergence with two significant breaks in level and trend. In estimating the β-convergence, for stochastic convergent countries with one-break, we impose $\zeta_3 = \zeta_5 = 0$ and with no break, we further impose $\zeta_2 = \zeta_4 = 0$.

2. Empirical findings

The unit root tests of each country's relative income to the average income of G7 countries are displayed in Table 3. We employ the Model C of Lee and Strazicich (2003) to examine relative income series, while allowing for two breaks in the regression. Furthermore, we are able to reject the null of unit root for Germany and the US; and France at five and one percent significance levels, respectively which indicate stochastic convergence of these countries' income towards the average G7 income. For Canada, Italy, Japan and UK, we are not able to reject the null of unit root, illustrating idea of no convergence of these countries towards the G7 average. Excluding Bernard and Durlauf (1996), our findings are relatively at variance with the previous studies. The findings on break dates reveal some interesting observations. About 47% of the breaks lie within the Second World War of 1937-1949, while about 13% of breaks fall within the range of First World War of 1912-1927. Identical to the previous studies, it is obvious that most breaks occur around the two wars. Despite the evidence provided by the preceding results, pairwise stochastic convergence within the countries is further investigated[3].

Table 3. *G7 Average unit root tests*

Test	Lee and Strazicich test				
Country	k	T_{B1}	T_{B2}	T-Stat	Break point(s)
Canada	3	1916	1943	-4.719	(0.4, 0.6)
France	3	1938	1951	-8.090***	(0.4, 0.6)
Germany	8	1943	1957	-5.773**	(0.4, 0.6)
Italy	1	1912	1946	-4.679	(0.4, 0.6)
Japan	8	1943	1967	-5.076	(0.6, 0.8)
UK	8	1960	-	-3.182	(0.6)
US	8	1937	1959	-5.716**	(0.4, 0.6)

Critical values for Lee and Strazicich (2003)

Y									
	0.4			0.6			0.8		
	10%	5%	1%	10%	5%	1%	10%	5%	1%
0.2	-5.27	-5.59	-6.16	-5.32	-5.74	-6.41	-5.33	-5.71	-6.33
0.4	-	-	-	-5.31	-5.67	-6.45	-5.32	-5.65	-6.42
0.6	-	-	-	-	-	-	-5.32	-5.73	-6.32

T_B is the estimated break points. *, **, *** imply 1%, 5% and 10% levels of significance.

Critical values in the lower panel of Table 3 are from Lee and Strazicich (2003), while the critical values for Lee and Strazicich (2004) one break tests are -5.05, -4.50 and -4.18 for at the 1, 5 and 10 % levels of significance.

In Table 4, the findings of stochastic convergence test of countries' incomes in a pairwise framework are shown. We are able to reject the null in favour of convergence in nine cases out of the possible 21 bilateral convergence links. Canada income converges with incomes of three European countries i.e. France, Italy and Germany, without converging with income of its neighbour, the US. This can be explained by the fact that Canada and EU countries are similar in aspect of lower factor mobility than in the US. More interesting is that the income of the three Eurozone countries in the sample (France, Italy and Germany) converges, whereas there is no convergence between UK and these Eurozone countries. More countries converge to US's income than any other country. Japan's income is noted as not converging with other countries' income. Despite experiencing miraculous economic growth in the post-war period (Yamamura, Shin, 2008), several factors may account for no convergence of Japan's income with other countries such as shocks to international economy in 1973 (Webber, 2001) changed in fortunes of the world economy since 1980s (Linden, 1980) and the collapsed of the bubble economy in the early 1990s (Seya, Tsutsumi, Yamagata, 2012).

Table 4. *Pairwise unit root tests*

Test	Lee and Strazicich test				
Country	k	T_{B1}	T_{B2}	T-Stat	Break point(s)
France-Canada	4	1938	1951	-5.368*	(0.4, 0.6)
Germany-Canada	6	1943	1957	-5.688**	(0.4, 0.6)
Italy-Canada	8	1938	1956	-5.383*	(0.4, 0.6)
Japan-Canada	0	1958	-	-3.423	(0.4)
UK-Canada	4	1927	1945	-4.553	(0.4, 0.6)
US-Canada	8	1916	1947	-4.300	(0.4, 0.6)
Germany-France	5	1933	1948	-5.391*	(0.4, 0.6)
Italy-France	8	1911	1924	-5.407*	(0.2, 0.4)
Japan-France	1	1920	1965	-4.940	(0.4, 0.6)
UK-France	2	1938	1951	-4.900	(0.4, 0.6)
US-France	8	1938	1955	-6.628***	(0.4, 0.6)
Italy-Germany	1	1906	-	-5.292***	(0.2)
Japan-Germany	5	1922	1956	-4.436	(0.4, 0.6)
UK-Germany	0	1944	1957	-4.631	(0.4, 0.6)
US-Germany	7	1942	1959	-5.590*	(0.4, 0.6)
Japan-Italy	8	1905	1965	-4.240	(0.2, 0.6)
UK-Italy	7	1959	-	-3.024	(0.6)
US-Italy	7	1938	1956	-4.875	(0.4, 0.6)
UK-Japan	2	1943	1969	-4.206	(0.6, 0.8)
US-Japan	1	1959	-	-3.836	(0.6)
US-UK	8	1928	1941	-7.561***	(0.4, 0.6)

T_B is the estimated break points. *, **, *** imply 1%, 5% and 10% levels of significance.

Finally, we test for β-convergence for the France, Germany and the US that were established as stochastically convergent countries, using the G7 average income. The results are presented in Table 5, which illustrate that France coefficients are not significant. Although Germany's coefficients are significant, they do not produce the required opposite signs. By contrast, the US appears to satisfy the β-convergence by producing the required signs. This indicates that US is the only country that conditionally converges to the average of G7 countries. Difference in findings between our studies and the previous studies may be due to the inclusion of recent data that includes the period of economy downturn in most G7 countries. The reason is further substantiated with the fact that US suffer the lowest slump of income among these countries, but satisfies both stochastic convergence and β-convergence.

Table 5. *β-convergence for G7 countries*

Country	Intercept and trend	
	τ	β
France	-0.136	-0.001
Germany	-0.045***	-0.003***
US	0.140**	-0.002***

 *, **, *** implies significance at 10, 5 and 1%, respectively.
The Newey-West estimator is applied to correct for possible serial correlation and heteroscedasticity.

3. Conclusions

Arising from the fact that testing convergence of national incomes is a means of validating exogenous growth of the Solow model, empirical scholarships on convergence of developed countries outputs have been well documented. Most existing studies consider OECD countries, which actually has emerging economies as members as representative of developed countries. However, studies specifically on G7 countries (Canada, France, Germany, Italy, Japan, UK, and the US), which truly symbolize developed countries, are virtually non-existent. In this study, we examine the occurrence of stochastic convergence in G7 countries for the 1870-2008 period using Lee and Strazicich (2003) unit root tests. In addition to utilising the mean of G7 income as benchmark in a multivariate system, we also investigate stochastic convergence in a pairwise (bivariate) system. We further probe *β*-convergence as proposed by Carlino and Mills (1993) who termed its occurrence as sufficient condition of conditional convergence. Out of the possible 21 pairwise stochastic convergence cases, we observe nine pairwise stochastic convergence cases. These include three cases in which Eurozone countries converging with each other, but sharing no convergence with UK. Japan appears as the only country that is not stochastically converging with any of the

countries. Although Germany, France and the US stochastically converge towards the G7 average, only US conditionally converges to the average of G7 countries.

Notes

[1] An exception is Romero-Ávila (2009), who considered the OECD for the period of 1870-2003. While our methodology (like the other works cited) is within a time series frame work, Romero-Ávila based his work on panel technique.

[2] We consider G7 as against G8 for several reasons. Although Russia joined the G7 to form the G8 in 1997, G7 still retains some features of its Pre-Russia membership years as some meetings continued to be held in G7 format. Moreover, Russia, unlike most other members, cannot be considered as fully industrialized. Lastly, data for Russia is not available for such a long time span.

[3] Pesaran (2007) have introduced a novel approach, in which convergence does not only require the rejection of the null hypothesis of unit root but also co-trending restrictions (in which the linear trend must be insignificant) for convergence hypothesis to hold in a pair wise setting. However, it may be criticized as it neglects possible structural breaks in output gap long-run value due to changes in the structural parameters of economies (Le Pen, 2011).

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