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Time Series Tests of Income Convergence with Two Structural Breaks: An Update and Extension

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Abstract

This paper uses newly available long-span data on real per capita incomes from 1900-2001 to test for stochastic convergence in a diverse group of 29 countries. To perform our tests, we utilize the two-break LM unit root test of Lee and Strazicich (2003) and endogenously determine two distinct structural breaks in level and trend for each country. Despite including both OECD and non-OECD countries, we find significant evidence that incomes are stochastically converging in 23 of the 29 countries. World War II is the most often identified time period of structural breaks in relative income.

JEL classification: O40, C12

Keywords: Convergence; structural breaks; unit root test

1. Introduction

Since Friedman's (1992) criticism of cross-section tests of the convergence hypothesis, alternative time-series tests for income convergence have been often explored. Such time-series tests generally use unit root or cointegration techniques to test for convergence. See, for example, the studies by Carlino and Mills (1993), Bernard and Durlauf (1995), Loewy and Papell (1996), Li and Papell (1999), Datta (2003), Strazicich, Lee, and Day (2004), and Dawson

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and Sen (forthcoming), among others.[1] Carlino and Mills (1993) and Loewy and Papell (1996) use unit root tests and find support for income convergence among the U.S. regions. Whereas Carlino and Mills (1993) utilize one exogenous and identical break in each region, Loewy and Papell (1996) find stronger support utilizing one endogenous break that is distinct to each region. Bernard and Durlauf (1995) utilize cointegration tests in a framework without structural breaks and find little support for income convergence among 15 OECD countries. Li and Papell (1999) employ a unit root test with one endogenously determined break and find evidence of convergence in 14 of 16 OECD countries. More recently, Datta (2003) allows for structural changes by utilizing a Kalman filter procedure and finds support for convergence among OECD countries for the time period 1950-1993. Strazicich, Lee, and Day (2004) utilize a two-break LM unit root test to test for convergence in 15 OECD countries for the time period 1870-1994, and find evidence of convergence in nearly all countries. Dawson and Sen (forthcoming) use Dickey-Fuller type unit root tests with one endogenously determined break and find evidence of convergence in 21 countries using a sample of 29 OECD and non-OECD countries.

In this paper, we apply the two-break LM unit root test used by Strazicich, Lee, and Day (2004) to the 29 countries considered in Dawson and Sen (forthcoming) for the sample period 1900-2001. In comparison to these works, we consider a larger and more diverse group of countries than in Strazicich, Lee, and Day (2004) and allow one more structural break than in Dawson and Sen (forthcoming). An additional advantage of the endogenous break LM test is that the test is free of spurious rejections in the presence of a unit root with break. Our findings provide significant evidence that incomes are stochastically converging. World War II is identified as the most frequent time period of structural breaks in relative incomes.

The remainder of the paper is organized as follows. Section 2 briefly reviews the two-break LM unit root test, discusses its properties, and presents the empirical results. Section 3

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[1] In this paper, we restrict our attention to those studies using univariate time-series tests for convergence.

concludes.

2. Time-series tests for convergence

Most time-series tests of convergence are related to the notion of “stochastic convergence” as described in Carlino and Mills (1993). Stochastic convergence implies that shocks to the income of a given country relative to the average income across a group of countries will be temporary. Thus, a common test for stochastic convergence involves testing for a unit root in the log of the ratio of per capita income relative to the group average. Failure to reject the unit root null hypothesis is evidence of divergence, while rejection of the unit root null supports stochastic convergence.

The standard approach to test for a unit root involves performing augmented Dickey-Fuller (ADF) unit root tests. However, Perron (1989) showed that conventional ADF unit root tests can fail to reject the unit root null hypothesis when a time series is characterized as stationary around a breaking trend. Perron (1989) proposed allowing for one *exogenous* or known structural break in the ADF test. Subsequently, Zivot and Andrews (1992) and Perron (1997), among others, proposed to determine the location of the break *endogenously* from the data.

A potential problem common to the ADF-type endogenous break unit root tests is that they typically derive their critical values while assuming no break(s) under the null hypothesis. This assumption leads to over-rejections in the presence of a unit root with break (see Nunes et al. (1997) and Lee and Strazicich (2001, 2003)). As a result, “spurious rejections” in the use of ADF-type endogenous break tests can lead researchers to conclude that a time series is trend stationary when, in fact, the series is nonstationary with break(s). To avoid these potential problems, Lee and Strazicich (2003) propose a LM unit root test that allows for two endogenously determined breaks in the level and trend slope. Our analysis below applies the two-break LM unit root test to the long-span data examined by Dawson and Sen (forthcoming).

Following Lee and Strazicich (2003), we utilize *k** lagged first-differenced terms to correct for serial correlation and determine *k** by the "general-to-specific" procedure.[2]

Our data consists of annual time series on per capita real GDP over the period 1900-2001, as reported in Maddison (1995, 2003).[3] The countries included are Argentina, Australia, Austria, Belgium, Brazil, Canada, Chile, Columbia, Denmark, Finland, France, Germany, India, Italy, Japan, Mexico, the Netherlands, New Zealand, Norway, Peru, Portugal, Spain, Sri Lanka, Sweden, Switzerland, the United Kingdom, the United States, Uruguay, and Venezuela. For each country, we examine the natural logarithm of the ratio of per capita real GDP relative to the aggregate per capita GDP of the group. Specifically, we take the natural logarithm of each individual country's per capita real GDP divided by the aggregate per capita real GDP, which is calculated by summing real GDP from the 29 countries and dividing by the total population of these countries.

The results of using the two-break LM unit root test are reported in Table 1. In 22 of the 29 log relative income series, we reject the unit root null and, thus, reject divergence at the 10% significance level. The 7 countries for which we cannot reject the unit root null are Australia, Japan, Portugal, Spain, Sri Lanka, the U.K., and Uruguay. Further examination of these results reveals that two structural breaks in level and/or trend are significant (*t*-values significant at 10%) in 25 countries, while only one structural break is significant in the four remaining countries (Australia, Norway, Sri Lanka, and Switzerland).[4] The most frequently identified time

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[2]While one might suggest allowing for more than two breaks in the unit root test, we do not consider this possibility here for the following reasons: (1) the computational burden of identifying three or more break points in conjunction with determining the optimal number of lagged augmented terms would significantly increase; (2) allowing for more than two breaks may not be a concern here since we find that two breaks are, in general, sufficient to reject the unit root null.

[3]See the Data Appendix for additional details on the construction of the data set.

[4]Recall that the LM unit root test allows for the possibility of structural breaks under the unit root null hypothesis, so that breaks in the intercept and trend represent one-period jumps in level and permanent shifts in level, respectively, under the null hypothesis and shifts in level and trend, respectively, under the stationary alternative hypothesis.

period of breaks is in the years 1938-1948 surrounding World War II (approximately 35% of the breaks). Also noteworthy is that five Latin American countries (Argentina, Brazil, Chile, Mexico, and Peru) have structural breaks in their relative income during the period of 1979-1986. This time period is known to be one of debt crisis and economic collapse for many countries in this region of the world (see, e.g., Hopenhayn and Neumeyer (2004)).

As noted, a one-break unit root test appears to be more appropriate for Australia, Norway, Sri Lanka, and Switzerland. In addition, including two breaks when only one is present can adversely affect power to reject the null for these countries. To check for this possibility, we perform additional tests for these four countries using the one-break minimum LM unit root test (Lee and Strazicich (2004)). These results are displayed in Table 2. For Norway and Switzerland, countries for which the unit root null was rejected at the 10% level in the two-break test, we can now reject the unit root null at the stronger 5% and 1% levels, respectively. The breaks for these countries are significant at the 10% level. Australia and Sri Lanka were countries for which we could not reject the unit root null hypothesis in the two-break tests. Using the one-break test, we can now reject the unit root null in Australia at the 10% level. However, the break is not significant at the 10% level. We are still not able to reject the unit root null for Sri Lanka, although the break is significant at the 10% level.

Since the estimated break for Australia was not significant (at the 10% level), a unit root test without a break may be more appropriate. We consider the conventional ADF test. When both an intercept and trend are included in the test equation, the unit root null cannot be rejected at the 10% level. However, the trend term is not statistically significant at the 10% level. When the trend term is removed from the test equation, the unit root null is rejected at the 5% level, with a *t*-test statistic of −2.93. Thus, including Australia, we can reject divergence in 23 (79%) of the 29 countries.[5]

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[5]We additionally performed our unit root tests with breaks using the natural log of per capita income relative to U.S. income rather than the group mean. These results were qualitatively similar to the results reported

In comparison with the results reported in Dawson and Sen (forthcoming), we find more evidence of stochastic convergence. We find evidence to reject divergence in 23 countries as compared to their 21. Both studies agree on the lack of stochastic convergence in four countries: Japan, Portugal, Sri Lanka, and the U.K. The studies also agree on the lack of a significant break for Australia. Finally, our findings are consistent with previous works in identifying the World War II period as the most frequent time of structural breaks.

3. Concluding remarks

This paper tests for stochastic convergence by utilizing long-span time series on real per capita incomes from 29 OECD and non-OECD countries–the largest and most diverse group of countries for which long-span data is currently available. To perform our tests, we utilize LM unit root tests that allow for two distinct endogenously determined structural breaks in level and trend in each country's relative income series. At least one significant break is found in all but one country (Australia) and World War II is the most often identified time period of breaks. Overall, our findings provide significant evidence of stochastic convergence in 23 of the 29 countries. In general, these findings are consistent with most previous studies that examined time series of OECD countries, but more robust since they include both OECD and non-OECD countries *and* allow for two structural breaks.

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above. Overall, using income relative to the U.S., we found evidence of stochastic convergence in 20 (71%) of the 28 countries. Again, the most frequently identified time period of breaks is the World War II period of 1938-1948 (37.5% of breaks). These results are available upon request.

Data Appendix

All data are from Maddison (2003), with the following exceptions to maintain border consistency throughout the sample period.

Germany: Data from the 1900-1994 period are from Maddison (1995), based on German boundaries in 1989. Data from 1995-2001 are determined by applying growth rates implicit in the Maddison (2003) data to the (1995) data, since the (2003) data are based on current boundaries for the re-unified Germany.

United Kingdom: Data from Maddison (2003), except that data for 1921-2001 was adjusted to include Ireland to maintain consistency with the pre-1921 data. Figures for the U.K. and Ireland were summed for 1921-2001 using data for each country from Maddison (2003).

India: Data from Maddison (2003), except that data for the 1947-2001 time period was adjusted to include Bangladesh and Pakistan to maintain consistency with the pre-1947 data. Figures for India, Bangladesh and Pakistan are summed for the 1947-2001 period, using data on each country from Maddison (2003) with the following exceptions. The growth rates of GDP and population from 1946-47 implicit in Maddison (1995) are applied to the 1946 figure in Maddison (2003) to obtain GDP and population figures for 1947. Population figures from 1948-49 are obtained by adding population estimates for India, Bangladesh, and Pakistan from Maddison (1995).

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Table 1: Two-Break Minimum LM Unit root Tests, 1900-2001

Country	k*	T_{B1}, T_{B2}	Test Statistic	λ used for critical values
Argentina	7	1944, 1985	−5.497*	λ = (0.4, 0.8)
Australia	1	1932n, 1954	−5.021	λ = (0.4, 0.6)
Austria	3	1943, 1953	−6.195**	λ = (0.4, 0.6)
Belgium	8	1917, 1940	−6.322***	λ = (0.2, 0.4)
Brazil	3	1973, 1979	−6.036**	λ = (0.6, 0.8)
Canada	5	1916, 1943	−5.582*	λ = (0.2, 0.4)
Chile	1	1947, 1986	−6.158**	λ = (0.4, 0.8)
Columbia	1	1934, 1972	−5.392*	λ = (0.4, 0.8)
Denmark	3	1938, 1947	−7.253***	λ = (0.4, 0.6)
Finland	8	1913, 1928	−5.679**	λ = (0.2, 0.4)
France	3	1938, 1948	−7.578***	λ = (0.4, 0.6)
Germany	5	1943, 1955	−5.580*	λ = (0.4, 0.6)
India	6	1940, 1980	−5.621*	λ = (0.4, 0.8)
Italy	1	1941, 1948	−5.714**	λ = (0.4, 0.6)
Japan	4	1943, 1964	−4.962	λ = (0.4, 0.6)
Mexico	2	1931, 1986	−5.343*	λ = (0.4, 0.8)
Netherlands	1	1939, 1947	−7.907***	λ = (0.4, 0.6)
New Zealand	4	1924, 1946	−5.570*	λ = (0.2, 0.4)
Norway	1	1931, 1940n	−5.478*	λ = (0.2, 0.4)
Peru	7	1952, 1986	−5.818**	λ = (0.6, 0.8)
Portugal	2	1913, 1964	−4.818	λ = (0.2, 0.6)
Spain	8	1934, 1962	−4.880	λ = (0.4, 0.6)
Sri Lanka	5	1929, 1971n	−4.694	λ = (0.2, 0.6)
Sweden	4	1915, 1947	−6.067**	λ = (0.2, 0.4)
Switzerland	1	1909n, 1949	−5.520*	λ = (0.2, 0.4)
U.K.	7	1931, 1969	−4.594	λ = (0.4, 0.6)
U.S.	8	1938, 1957	−5.544*	λ = (0.4, 0.6)
Uruguay	2	1957, 1972	−5.176	λ = (0.6, 0.8)
Venezuela	3	1924, 1959	−6.100**	λ = (0.2, 0.6)

Notes: k* is the optimal number of lagged first-difference terms included in the unit root test to correct for serial correlation. T_{B1} and T_{B2} denote the break dates. n denotes that the identified break point was not significant at the 10% level. Critical values at different break points for a sample size T = 100 are reported in Strazicich *et al.* (2003), Table 1. Critical values at other break points can be interpolated. *, **, and *** denote significance at the 10%, 5%,and 1% levels, respectively.

Table 2: One-Break Minimum LM Unit root Tests, 1900-2001

Country	k*	T_B	Test Statistic	λ used for critical values
Australia	1	1978n	−4.283*	λ = 0.8 (= 0.2)
Norway	7	1981	−4.852**	λ = 0.8 (= 0.2)
Sri Lanka	0	1977	−3.258	λ = 0.8 (= 0.2)
Switzerland	1	1949	−5.123***	λ = 0.5

Notes: k^* is the optimal number of lagged first-difference terms included in the unit root test to correct for serial correlation. T_B denotes the break date. n denotes that the identified break point was not significant at the 10% level. Critical values at different break points for a sample size T = 100 are reported in Strazicich *et al.* (2004), Table 2. Critical values at other break points can be interpolated. *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively.