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Are Real GDP Levels Trend, Difference, or Regime-Wise Trend Stationary? Evidence from Panel Data Tests Incorporating Structural Change

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Abstract:

The unit root hypothesis for international real GDP and real GDP per capita has been the subject of extensive investigation. Using panel methods that incorporate structural change, we reject the unit root null in favor of the alternative of trend stationarity with one or two changes in the slope for two panels with postwar data and one or two changes in both the slope and the intercept for a panel with long-horizon data. We conclude that real GDP levels are better characterized as regime-wise trend stationary than as either trend stationary without structural change or difference stationary with unit roots.

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1. Introduction

The evidence in Nelson and Plosser (1982) that the unit root hypothesis cannot be rejected for most long-term U.S. macroeconomic time series ran contrary to many economic theories that relied on the idea of cyclical fluctuations around stable long run trends and set off an explosion of research. Real GDP, real exchange rates, and real interest rates are among the many variables for which the unit root question has been investigated.

A common criticism of unit root tests, notably the Augmented-Dickey-Fuller (ADF) test, is that they have low power against persistent, but stationary, alternatives with normally available time spans of data. One response to this criticism has been the development of panel unit root tests, such as Levin, Lin, and Chu (2002), Im,Pesaran and Shin (2003), and Maddala and Wu (1999) that exploit the cross-section, as well as the time series dimension of the data in order to increase power. These tests have been successful in finding evidence of stationarity that cannot be found by univariate methods, particularly for real exchange rates.[1]

In a recent article, Rapach (2002) examined four international data sets of real GDP and real GDP per capita which he divided into a variety of panels. He tested the panels using a variety of panel unit root tests, and is rarely able to reject the unit root for his many combinations of panel, test, and lag length. He concludes that "the results overwhelmingly indicate that international real GDP and real GDP per capita levels are nonstationary." These results are important because, since the panel unit root tests employed have good power for the time series and cross section dimension of the data, they show that previous failures to reject the unit root hypothesis for international real GDP were not caused by the low power of ADF tests.

The central point of this paper is that Rapach's results that the unit root null cannot be rejected against a level stationary alternative does not constitute evidence that international real GDP and real GDP per capita levels can be characterized by unit roots. Using panel methods, we show that there is strong evidence that the unit root null can be rejected against an alternative hypothesis of stationarity with one or two structural

[1] Papell (1997) studies unit roots in real exchange rates with univariate and panel methods.

changes in either the slope or in both the intercept and the slope of the international real GDP series. Our research was inspired by the last paragraph of Rapach's paper, which suggests that, with univariate methods, the unit root null can be rejected more frequently once structural breaks are allowed in deterministic trends for long-horizon, as in Ben-David and Papell (1995), but not postwar, as in Cheung and Chinn (1996), international real GDP series.

In order to focus on issues involving structural change, we start by using the same data analyzed by Rapach: annual real GDP from 1956-1996 for 13 countries, annual real GDP per capita from 1950-1992 for 21 countries, and annual real GDP per capita from 1900-1987 for 15 countries.[2] While this is useful to provide a benchmark for our results, it obviously does not utilize all available data. We therefore also estimate panels for which the data is extended to 2003, providing a common end point.

For the long-horizon annual real GDP per capita data set, we want to incorporate potential structural change in the level of the series from events such as World War I, World War II, and the Great Depression, as well as possible changes in growth rates. Since the level of GDP cannot change instantaneously, but is necessarily spread out over time, we estimate Innovational Outlier (IO) models, for which the effects of the structural change can occur slowly, that allow for a one-time change in both the intercept and the slope of the series. For the two postwar data sets, where no events of comparable magnitude have occurred, the potential structural change is in growth rates, such as may have occurred during the growth slowdown of the 1970s, but not in levels. Since growth rates can change quickly, we estimate Additive Outlier (AO) models, for which the effects of the structural change occurs instantaneously, that allow for a one-time change in only the slope of the series.

We first conduct panel unit root tests that do not allow for structural change. For each panel, we simulate critical values under the unit root null that reflect the exact number of observations, serial correlation, and contemporaneous correlation present in the actual data. The unit root null cannot be rejected (at the 10 percent significance level) in favor of the trend stationary alternative for any of the six panels. This both confirms

[2] Rapach also reports results with quarterly real GDP from 1965(1)-1996(4) for 7 countries. Since the power of panel unit root tests depends primarily on the span of the data and number of countries, but not the frequency of observation, this panel does not add anything to the analysis using annual real GDP data.

Rapach's results and demonstrates that they are unchanged by the inclusion of additional data.

We proceed to develop panel unit root tests that incorporate a one-time structural change. Murray and Papell (2000) construct an AO panel unit root test which allows a single common structural break in non-trending data, which they apply to panels of OECD annual unemployment rates. We extend their technique to trending data, and develop AO models that allow for a slope change and IO models that allow for both an intercept and a slope change.

For Rapach's original data, the results of the panel unit root tests in the presence of a one-time structural change are extremely strong. The unit root null can be rejected at the 1 percent significance level using an AO model for panels with postwar annual real GDP and real GDP per capita data and at the 5 percent significance level using an IO model for the panel with long-horizon annual real GDP per capita data. The breaks occur in the early 1970s for the postwar data and at the start of World War II for the long-horizon data. A different picture emerges when the data is extended through 2003. While the unit root null is still rejected at the 1 percent level for the panel with postwar annual real GDP per capita data and at the 10 percent significance level for the panel with long-horizon annual real GDP per capita data, it is not rejected (at the 10 percent level) for the panel with postwar annual real GDP data.

We conjecture that, with the additional data, the effects of the growth slowdown of the 1970s might be counteracted by the resumption of higher growth in the 1980s and 1990s, and therefore construct panel unit root tests that incorporate two structural changes. Using these tests, we reject the unit root null at the 1 percent level in favor of broken trend stationarity for all three panels. For the two postwar panels, the first break is in the early 1970s and the second is in the mid-1980s or early 1990s while, for the long-horizon data, the first break is at the start of World War II and the second is in the mid-1960s. We conclude that real GDP levels are better described as regime-wise trend stationary with two structural changes in either the slope or in both the intercept and the slope than as either trend stationary without structural change or difference stationary with unit roots.

2. Panel Unit Root Tests without Structural Change

Panel unit root tests have been widely used in the last decade to investigate stationarity when the span of the data is too short for univariate tests to have sufficient power. Rapach (2002) uses a battery of different panel data techniques on real GDP and real GDP per capita data sets, and is unable to reject the unit root null hypothesis in almost all cases. We use data from Rapach (2002) which includes three data sets of international real GDP and per capita real GDP time series, all in log levels. The three data sets are described as follows:

- Annual real GDP data for the time period 1956 to 1996 for 13 countries published in the International Monetary Fund's *International Financial Statistics* (IFS). The countries include: Australia, Canada, Denmark, France, Ireland, Japan, the Netherlands, New Zealand, Norway, Spain, Switzerland, the UK, and the US. We extend the data through 2003 using more recent IFS data.[3]
- Annual real GDP per capita data for the time period 1950 to 1992 for 21 countries published in the Penn World Tables (PWT). The countries include Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Iceland, Ireland, Italy, Japan, Luxembourg, the Netherlands, New Zealand, Norway, Spain, Sweden, Switzerland, the UK, and the US. We extend the data through 2003 using more recent PWT data.
- Annual real GDP per capita data for the time period 1900 to 1987 for 15 countries from Bernard and Durlauf (1995, hereafter referred to as BD). The countries include Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Italy, Japan, the Netherlands, Norway, Sweden, the UK, and the US. We extend the data through 2003 using more recent IFS data.[4]

Panel unit root tests with trending data can be conducted by running the following regressions:

$$\Delta y_{jt} = \mu_j + \beta_j t + \alpha y_{jt-1} + \sum_{i=1}^{k_j} c_{ji} \Delta y_{jt-i} + \varepsilon_{jt} \qquad (1)$$

[3] We do not extend the data past 2003 in order to have a common ending date for all three panels.

[4] We also conducted the tests with annual real GDP per capita data for the same time period from Maddison (2003), and the results were very similar to those with the BD data.

The subscript $j = 1,\ldots,N$ indexes the countries within the panel. We allow heterogeneous intercepts, time trends, and lag lengths. Equation (1) is estimated by feasible GLS (SUR), with the number of lagged differences k determined by individual univariate ADF tests using the general-to-specific method suggested by Campbell and Perron (1991) and Ng and Perron (1995). First an upper bound k_{max} is selected for k. If the last lagged difference is significant, k is set to equal k_{max}. If not, k is reduced by one and the process is repeated until the last lagged difference is significant. We set $k_{max} = 8$ for the series, BD annual real GDP per capita, with more than 50 observations and set $k_{max} = 4$ for the two series, IFS annual real GDP and PWT annual real GDP per capita, with fewer than 50 observations, and use a critical value of 1.645 from the asymptotic normal distribution to assess significance. The null hypothesis of a unit root is rejected if the absolute value of the t-statistic on α is greater than the appropriate critical value.

The null hypothesis is that all of the series contain a unit root and the alternative hypothesis is that all of the series are trend stationary. We restrict the α's to be homogeneous across countries, as in Levin, Lin, and Chu (2002), rather than letting them be heterogeneous, as in Im, Pesaran, and Shin (2003), because, for the latter class of tests, the alternative hypothesis is that at least one, rather than all, of the series are stationary. Even though the assumption of homogeneous α's may be restrictive, we do not see what can be learned from rejecting the unit root null in favor of the alternative that at least one out of 13, 15, or 21 countries are stationary.[5]

Since the distributions of the panel unit root tests are non-standard, we use Monte Carlo methods to calculate critical values which reflect both the number of countries in the panel and the exact number of observations and account for both serial and contemporaneous correlation. For each span of the data, we first assume the unit root null is true and fit univariate autoregressive (AR) models to the first differences of the 20 real exchange rates, using the Schwarz criterion to choose the optimal AR model. Treating the estimated AR coefficients as the true parameters, we treat the optimal estimated AR models as the true data generating processes for the errors in each of the

[5] This distinction would be irrelevant if one could assume that either all of the series in a panel were stationary or that all of the series had unit roots. We do not, however, see any justification for precluding mixed panels that include both stationary and unit root series. Bowman (1999) shows that, with mixed panels, tests that impose homogeneity are more conservative than tests that allow heterogeneity.

series, and construct real exchange rate innovations from the residuals. We then calculate the covariance matrix Σ of the innovations and use the optimal AR models with iid $N(0,\Sigma)$ innovations to construct pseudo samples of size equal to the actual size of our series.[6] Since Σ is not diagonal, this preserves the cross-sectional dependence found in the data. We then take partial sums so that the generated data has a unit root by construction.[7]

We proceed to perform the estimation procedure described above on the generated data. For each panel, we first estimate univariate ADF models for the series, using the recursive t-statistic procedure to select the value of k. We then estimate Equation (1) using feasible GLS (SUR), with the values for k taken from the results of the univariate ADF tests. Repeating the process 5,000 times, the critical values for the finite sample distributions are taken from the sorted vector of the replicated statistics.

Since Rapach uses fixed lag lengths and we use general-to-specific lag selection techniques, we first run panel unit root tests without structural change on his data as a benchmark. The results of the panel unit root tests without structural change are presented in the top panel of Table 1. As in Rapach (2002), the unit root null cannot be rejected in favor of the trend stationary alternative for any of the three panels at standard significance levels. We then run the same tests on the same panels with the data extended to 2003. The results are identical. The unit root null cannot be rejected in favor of the trend stationary alternative for any of the three panels. These results both replicate (with a slightly different estimation procedure) the results reported by Rapach and show that his results do not change with the extended data.

3. Panel Unit Root Tests with Structural Change

One potential reason for non-rejection of the unit root null is the possibility that, while most of the deviations from the long run trend are transitory, there may be one or

[6] In order to eliminate the effects of initial values, we generate 50 more observations than the length of each series, and then discard the first 50 simulated data points.

[7] The PWT annual real GDP per capita data had too many countries, 21, relative to the number of observations, 43, to allow for cross-sectional dependence under the null. For this panel, we calculated critical values with $N(0,1)$ innovations. We performed the same calculation for the other three panels, and the critical values with $N(0,1)$ innovations were similar to those with $N(0,\Sigma)$ innovations.

more that are permanent, thereby changing the long run trend itself. Perron (1989) has shown that a series that is stationary around an occasionally changing trend will mimic the behavior of a random walk and therefore not allow a rejection of the unit root. Our objective in this section is to develop panel unit root tests that allow for structural change and to see if the unit root null can be rejected in favor of the alternative of trend stationarity with a one or two-time change in either the slope or in both the intercept and the slope.

Unit root tests in the presence of structural change can be run in an AO framework where the change in the trend occurs instantaneously or in an IO framework where the change occurs over time. Since no cataclysmic events that might be expected to produce a break in the intercept of real GDP for these countries have occurred since the end of World War II and growth rates can change instantaneously, we choose the AO model with a break in the slope for the two post-war data sets (IFS annual and PWT). Since the long horizon data includes the Great Depression, World War I, and World War II, events that can potentially cause both intercept and growth changes which may be spread out over several years, we choose an IO model with a simultaneous break in the slope and intercept for the longer BD data set.[8]

The test under the AO model involves a two stage process of first running the following regression:

$$y_{jt} = \mu_j + \beta_j t + \gamma_j DT_t + \rho_{jt} \tag{2}$$

where y_t is the natural log of real GDP or real GDP per capita, TB is the break date, and DT is the slope break dummy variable which equals (t-TB) for all t greater than TB and zero otherwise. The subscript j = 1,…,N indexes the countries within the panel. The residuals, ρ_t, are saved and regressed against their lagged value and lagged differences in the second stage of the process, by the following regression:

$$\Delta\rho_{jt} = \alpha\rho_{jt-1} + \sum_{i=1}^{k_j} c_{ji}\Delta\rho_{jt-i} + \varepsilon_{jt} \tag{3}$$

As with the panel unit root tests without structural change, the number of lagged differences k is determined by the general-to-specific method. The two regressions are estimated sequentially for each break year TB = k+2, …,T-1, where T is the number of

[8] We follow Perron (1989) in using an IO model for long-horizon data and an AO model for postwar data.

observations. The break date is chosen to minimize the t-statistic on α . The null hypothesis of a unit root is rejected if the absolute value of the minimum t-statistic on α is greater than the appropriate critical value.

For the BD data series, we use an IO model which involves running the following regression:

$$\Delta y_{jt} = \mu_j + \beta_j t + \alpha y_{jt-1} + \delta_j DU_t + \gamma_j DT_t + \sum_{i=1}^{k_j} c_{ji} \Delta y_{jt-i} + \varepsilon_{jt} \tag{4}$$

The variables are the same as in the AO model above with the addition of the intercept break dummy variable DU, which equals one for all *t* greater than TB and zero otherwise. The maximum lag length k is chosen in the same method as before. The regression is run for each possible break date and the break date is chosen to minimize the t-statistic on α.

We allow heterogeneous intercepts, time trends, δ's, γ's, and lag lengths. The lag lengths are determined by the individual univariate ADF tests and are chosen by general-to-specific procedures as discussed previously. Equations (3) and (4) are estimated by feasible GLS (SUR), with the values for k taken from the results of the univariate ADF tests. The break date is common across all countries of the panel and is chosen to minimize the test statistic, the t-statistic on α.[9] The critical values are calculated as described above for the panel tests without structural change, except that Equations (2) and (3) are estimated for the AO model and Equation (4) is estimated for the IO model.

The results for the panel unit root tests with a one-time structural change for Rapach's data are presented in the top panel of Table 2. We are able to reject the unit root null at the 1 percent level for the panels with IFS annual real GDP data and PWT annual real GDP per capita data, and at the 5 percent level for the panel with BD annual real GDP per capita in favor of trend stationarity with either a break in the slope (IFS and PWT) or a break in both the intercept and the slope (BD). This result is strikingly different from Rapach's (2002) panel unit root tests, and illustrates the importance of incorporating structural change in tests for unit roots in real GDP and real GDP per capita data. In the most dramatic case, PWT annual real GDP per capita data, the p-value of the

[9] While it would be possible to allow the break dates to differ across countries, much of the increase in power of the panel tests over the univariate tests comes from the imposition of the common break dates. If the series are regime-wise trend stationary with different break dates our methods will have low power to reject the unit root null.

panel unit root test falls from .990 without structural change to .000 with structural change. The breaks are 1973 for IFS annual real GDP data, 1971 for PWT annual real GDP per capita data, and 1940 for the panel with BD annual real GDP per capita, illustrating the importance of the 1970s growth slowdown for postwar data and World War II for long-horizon data.

The results change dramatically when the data is extended through 2003. As described in the bottom panel of Table 2, while the unit root null can still be rejected at the 1 percent level for the panel with PWT annual real GDP per capita data, it can only be rejected at the 10 percent level for the panel with BD annual real GDP per capita data and cannot be rejected at even the 10 percent level for the panel with IFS annual real GDP data. The breaks change only slightly - 1972 for IFS annual real GDP and PWT annual real GDP per capita data and 1939 for BD annual real GDP per capita data.

One possible reason for the weaker results with a longer span of data is that the single-break model is inadequate to capture the structural change with the extended data. The most obvious conjecture is that, while the single-break model can account for the growth slowdown of the 1970s, it cannot simultaneously account for the resumption of higher growth in the 1980s and 1990s.

We investigate these hypotheses by extending our methodology to account for two breaks. Univaraite tests for a unit root in the presence of two structural changes have been developed by Lumsdaine and Papell (1997), and we extend them to the panel context. The test under the AO model involves a two stage process of first running the following regression:

$$y_{jt} = \mu_j + \beta_j t + \gamma 1_j DT1_t + \gamma 2_j DT2_t + \rho_{jt} \tag{5}$$

where TB1 and TB2 are the break dates and DT1 and DT2 are the slope break dummy variables which equal (*t*-TB1) for all *t* greater than TB1, (*t*-TB2) for all *t* greater than TB2,and zero otherwise. The panel unit root tests are estimated according to Equation (3) where the ρ's are the residuals from Equation (5). The two regressions are estimated sequentially for each break year TB1 = k+2, …,T-1 and TB2 = k+2, …,T-1, where T is the number of observations.

The test under the IO model involves running the following regression:

$$\Delta y_{jt} = \mu_j + \beta_j t + \alpha y_{jt-1} + \delta 1_j DU1_t + \gamma 1_j DT1_t + \delta 2_j DU2_t + \gamma 2_j DT2_t + \sum_{i=1}^{k_j} c_{ji} \Delta y_{jt-i} + \varepsilon_{jt} \tag{6}$$

The variables are the same as in the AO model above with the addition of the intercept break dummy variables DU1 and DU2, which equal one for all *t* greater than TB1 and TB2 and zero otherwise. For both the AO and IO models, the break date is chosen to minimize the t-statistic on α over all possible combinations of TB1 and TB2, and the critical values are calculated by Monte Carlo methods as described above.

The results of the two-break tests are described in Table 3. Since the unit root null can be rejected in favor of regime-wise trend stationarity using a single-break model for all three panels with Rapach's original data, we only present results for the data extended to 2003. The unit root null can be rejected at the one percent level for all three panels, a much stronger result than obtained with the one-break tests. For the postwar series with only slope changes, the breaks are 1972 and 1991 for IFS annual real GDP data and 1973 and 1985 for PWT annual real GDP per capita data, illustrating both the growth slowdown in the 1970s and subsequent higher growth starting in the mid-1980s. For the BD annual real GDP per capita data, the breaks with both intercept and slope changes are 1939 and 1965, again illustrating the importance of World War II for analysis of long-horizon data.

4. Conclusions

The first objective of this paper is to investigate whether Rapach's (2002) failure to reject the unit root null in postwar and long-horizon real GDP and real GDP per capita data in favor of the trend stationarity alternative using panel methods survives the incorporation of structural change. Following Murray and Papell (2000), we combine the research areas of tests for a unit root in the presence of structural change and panel unit root tests, and extend the panel unit root testing methodology by including either a one-time change in the slope (postwar data) or a one-time change in both the intercept and the slope (long-horizon data) with trending data in the SUR panel unit root framework.

Using the same data, our results are dramatically different from Rapach's. While he is rarely able to reject the unit root for any panel, we are able to reject unit roots for panels of IFS annual real GDP data, PWT annual real GDP per capita data, and BD annual real GDP per capita data in favor of trend stationarity with either a break in the slope or a break in both the intercept and the slope.

The second objective of the paper is to investigate the impact of extending Rapach's data, which ends between 1987 and 1996, through 2003. Although the evidence against unit roots weakens with the tests that incorporate one structural change, we present very strong evidence against unit roots by using tests with two structural changes.

The most striking result in the paper is that we find evidence of regime-wise trend stationarity for postwar real GDP and real GDP per capita data after accounting for the 1970s growth slowdown. While Perron (1989) rejected the unit root null in favor of a trend stationary alternative for quarterly postwar U.S. real GDP with a single break that was imposed exogenously, Zivot and Andrews (1992) demonstrated that this rejection did not survive allowing the break date to be determined endogenously. By developing panel methods that incorporate two structural changes, we are able to provide evidence against unit roots that cannot be found with either univariate tests that incorporate structural change or panel tests that do not incorporate structural change.

Our results for long-horizon real GDP per capita are less striking. Ben-David and Papell (1995) reject the unit root null in long-horizon GDP per capita data in favor of the regime-wise stationary alternative for 8 out of 16 countries with univariate tests that incorporate one break in the intercept and slope and Ben-David, Lumsdaine, and Papell (2003) provide similar rejections for 12 out of 16 countries with univariate tests that incorporate two breaks in the intercept and slope. Given these univariate results, it is not surprising that panel methods that incorporate structural change would provide strong rejections with similar data.

We conclude that international real GDP and real GDP per capita levels are not well described as either trend stationary or difference stationary with unit roots. The evidence strongly favors the conclusion that they are regime-wise trend stationary with two structural changes in the slope for post World War II data and two structural changes in the intercept and the slope for century-long data.

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Table 1. Panel Unit Root Tests with No Structural Change

Rapach Data

Data Set	t-statistic	p-value	Critical Values 1 percent	5 percent	10 percent
IFS Annual Real GDP	-7.57	.557	-11.60	-10.29	-9.68
PWT Annual Real GDP Per Capita	-9.60	.990	-14.92	-13.98	-13.50
BD Annual Real GDP Per Capita	-8.11	.478	-10.29	-9.62	-9.29

Data Extended Through 2003

Data Set	t-statistic	p-value	Critical Values 1 percent	5 percent	10 percent
IFS Annual Real GDP	-7.76	.454	-10.79	-9.81	-9.29
PWT Annual Real GDP Per Capita	-8.93	.997	-13.75	-13.01	-12.65
BD Annual Real GDP Per Capita	-8.25	.352	-9.97	-9.44	-9.08

Table 2. Panel Unit Root Tests with One Structural Change

Rapach Data

Data Set	Model	Break	t-statistic	p-value	Critical Values		
					1 percent	5 percent	10 percent
IFS Annual Real GDP	AO	1973	-11.47	.006	-11.15	-10.08	-9.64
PWT Annual Real GDP Per Capita	AO	1971	-17.14	.000	-13.10	-12.36	-12.02
BD Annual Real GDP Per Capita	IO	1940	-14.71	.014	-14.85	-14.12	-13.76

Data Extended Through 2003

Data Set	Model	Break	t-statistic	p-value	Critical Values		
					1 percent	5 percent	10 percent
IFS Annual Real GDP	AO	1972	-9.26	.134	-10.78	-9.82	-9.44
PWT Annual Real GDP Per Capita	AO	1972	-14.23	.000	-12.79	-12.23	-11.94
BD Annual Real GDP Per Capita	IO	1939	-13.53	.079	-14.45	-13.72	-13.39

Table 3. Panel Unit Root Tests with Two Structural Changes

Data Extended Through 2003

Data Set	Model	Break1	Break2	t-statistic	p-value	Critical Values		
						1 percent	5 percent	10 percent
IFS Annual Real GDP	AO	1972	1991	-13.26	.000	-12.43	-11.71	-11.38
PWT Annual Real GDP Per Capita	AO	1973	1985	-18.80	.000	-16.14	-15.58	-15.28
BD Annual Real GDP Per Capita	IO	1939	1965	-18.52	.001	-17.85	-17.21	-16.88