Testing for structural change in panel data: GDP growth, consumption growth, and productivity growth

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Abstract

In this paper we first estimate the growth rates of real per capita GDP, real per capita Consumption, and Productivity (real GDP per worker) for the following panels of countries: (1) OPEC countries, (2) industrialized countries, and (3) based on geographic location. We then test for a structural change in the growth rates for each group and also attempt to identify the change point for each group. If there is a significant change, then the growth rates are estimated before and after the break for comparison. It is found that industrial countries, in general, experienced slowdowns in growth in the early 1970s, whereas less developed countries also experienced slowdowns in growth, but the timing of the slowdowns was in the mid to late 1970s.

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1. Introduction

It is known that a slowdown in growth rate appears to characterize many of the world's industrialized countries since the early 1970s. Ben-David and Papell (1998) proposed tests for determining the significance and the timing of slowdowns in economic growth. Ben-David and Papell found that most industrialized countries experienced postwar growth slowdowns in the late 1960s or early 1970s and developing countries tended to experience much more severe slowdowns which, in contrast with the more developed countries, began nearly a decade later. Bai, Lumsdaine, and Stock (1998) studied the dating of the slowdowns in postwar European and U.S. output growth. Bai et al. found that there is evidence of a break in postwar European and U.S. output growth. They also pointed out that the model of a single common break date is consistent with the data. Bai et al. considered a multivariate system with a single common break date, and found that a 90% confidence interval for the break is the second quarter of 1972 to the second quarter of 1975. Canjels and Watson (1997) estimated annual postwar growth rates of real GDP per capital for 128 countries by assuming there were no break points. Perron (1989, 1997) claimed that most macroeconomic time series are best constructed as stationary fluctuations around a deterministic trend function if allowance is made for the possibility of a shift in slope in 1973. Vogelsang (1997) confirmed that many macroeconomic time series have trend functions with parameters that are not constant over time.

In this paper we analyze the annual growth rates of real per capita GDP, real per capita consumption, and real GDP per worker for 131 countries over the postwar period. We extend the analysis of Canjels and Watson (1997) and Ben-David and Papell (1998) by including more countries and by pooling the countries into suitable panels. We use the theory developed in Kao and Emerson (2004, 2005) to estimate the annual growth rates for different groups of countries. We consider the following panels of countries: (1) OPEC countries; (2) industrialized countries; (3) panels based on geographic location, i.e., (*i*) Africa, (*ii*) U.S. and Canada, (*iii*) South and Central America, (*iv*) Asia, (*v*) Europe, and (*vi*) Australia; and (4) the entire world. We then use the theory developed in Emerson and Kao (2001, 2002) to test for structural change in the annual growth rates of real per capita GDP, real per capita consumption, and productivity (real GDP per worker) in each of the different panels. The break points are estimated for each series in each panel of countries. The growth rates in each of the series are then estimated before and after the break for comparison.

The organization of the paper is as follows. Section 2 introduces the model and assumptions and summarizes the testing methodology that is used. Section 3 describes the data. Section 4 focuses on the estimation of the annual growth rates in real per capita GDP, real per capita consumption, and productivity. We also discuss the results of the tests for structural change and the estimated break years. In addition, we provide a comparison of the prebreak and postbreak growth rates in each of the series for each of the panels considered. Section 5 summarizes the findings.

2. The Model and Assumptions

We follow the estimation and testing procedures developed in Kao and Emerson (2004, 2005) and Emerson and Kao (2001,2002). The following simple linear trend with one-way error component model is considered:

$$y_{it} = \alpha + \beta_t t + u_{it}, \tag{1}$$
$$u_{it} = \mu_i + v_{it},$$

$i = 1, ..., N$, $t = 1, ...T$, where $\{y_{it}\}$ are 1×1, β_t is the slope parameter, $\{\mu_i\}$ are the unobservable individual effects with $\mu_i \sim iid\left(0, \sigma_\mu^2\right)$, and $\{v_{it}\}$ are AR(1) stationary disturbance terms with

$$v_{it} = \rho v_{it-1} + \varepsilon_{it}, |\rho| < 1, \tag{2}$$

where $\varepsilon_{it} \sim iid\left(0, \sigma_\varepsilon^2\right)$. The μ_i are assumed to be independent of v_{it} and $v_{it} \sim \left(0, \sigma_v^2\right)$, $t = 2, ..., T$, where $\sigma_v^2 = \frac{\sigma_\varepsilon^2}{1-\rho^2}$. We assume $v_{i1} = \sum_{j=0}^{[\pi T]} \rho^j \varepsilon_{i1-j}$, where π is a parameter that governs the variance of the initial condition.

Once the estimations have been completed, we test for changes in the parameter β, where the change points are unknown. Following Emerson and Kao (2001) we test the null hypothesis

$$H_0 : \beta_t = \beta \text{ for all t},$$

against the alternative hypothesis that there is only one change point k, i.e.,

$$H_1 : \beta_t = \begin{cases} \beta_1 & \text{for } t = 1, ..., k \\ \beta_2 & \text{for } t = k+1, ..., T \end{cases}. \tag{3}$$

The test statistics that we use to test for a structural change in a panel of countries when the error term is $I(0)$ are

$$T_1 = \sup_{2 \le k \le T-1} \left| \sqrt{NT^3} \frac{1}{6\sigma_0} \left(\frac{k}{T}\right)^3 \left(\widehat{\beta}_k - \widehat{\beta}_T\right) \right|,$$

$$sup\mathrm{W}_1(k) = \underset{[Tr^*] \le k \le T-[Tr^*]}{sup} \mathrm{W}_1(k),$$

$$Mean\mathrm{W}_1(k) = \frac{1}{T} \sum_{k=[Tr^*]}^{T-[Tr^*]} \mathrm{W}_1(k),$$

and

$$Exp\mathrm{W}_1(k) = \log\left(\frac{1}{T} \sum_{k=[Tr^*]}^{T-[Tr^*]} \exp\left(\frac{1}{2}\mathrm{W}_1(k)\right)\right),$$

where

$$\mathrm{W}_1(k) = \frac{\sigma_v^2}{3\sigma_0^2} \mathrm{W}(k),$$

$$\mathrm{W}(k) = \frac{1}{\sigma_v^2} \frac{\left(\widehat{\beta}_{1k} - \widehat{\beta}_{2k}\right)^2}{\left[\left(\sum_{i=1}^N \sum_{t=1}^k (t - \bar{t}_{1k})^2\right)^{-1} + \left(\sum_{i=1}^N \sum_{t=k+1}^T (t - \bar{t}_{2k})^2\right)^{-1}\right]},$$

$$\sigma_0^2 = \frac{\sigma_\varepsilon^2}{(1-\rho)^2}.$$

These test statistics are appropriate for panel time-series data, and are described in detail in Emerson and Kao (2001). These tests are extensions of well known time series tests for structural change to panel time-series models.

3. Data

The data consist of four series of annual observations from the Penn World Table, version 5.6, as described in Summers and Heston (1991). The four series considered are RGDPCH, C, RGDPL, and RGDPW. The series RGDPCH gives real per capita GDP expressed in 1985 international prices using a Chain Index over the postwar period. The series C gives real consumption as a percentage of RGDPL. The series RGDPL gives real per capita GDP expressed in 1985 international prices using the Laspeyres Index. The two series C and RGDPL are used to construct a new series giving real consumption per capita. The series RGDPW gives real GDP per worker expressed in 1985 international dollars. We limit our analysis to those 131 countries with 20 or more annual observations in the series RGDPCH.

4. Estimation and Testing

The natural logarithms of real per capita GDP, real per capita consumption, and real GDP per worker for many countries are reasonably modeled by (1) and (2). Thus, the equation we use to estimate the growth rates in real per capita GDP is

$$\ln GDP_{it} = \alpha + \beta_t t + u_{it}, \tag{4}$$

$$u_{it} = \mu_i + v_{it},$$

$$v_{it} = \rho v_{it-1} + \varepsilon_{it}, |\rho| < 1. \tag{5}$$

The equations used to estimate the growth rates in real per capita consumption and real GDP per worker follow in a similar fashion with $\ln GDP_{it}$ replaced by $\ln CPC_{it}$ and $\ln GDPW_{it}$.

In order to compute the test statistic, $W_1(k)$, we need to estimate the variance component σ_0^2. In order to do this, we also need to estimate the autocorrelation coefficient ρ and the variance of ε_{it}, which is σ_ε^2. The parameter ρ can be easily estimated by

$$\widehat{\rho} = \frac{\sum_{i=1}^N \sum_{t=2}^T \widehat{v}_{it}\widehat{v}_{it-1}}{\sum_{i=1}^N \sum_{t=2}^T (\widehat{v}_{it-1})^2},$$

where $\widehat{v}_{it}$ is the estimated residual taken from (4). The variance component σ_ε^2 can be consistently estimated by the procedure described in Baltagi and Li (1991) when the disturbances are stationary.

In order to compute the test statistic, $W_2(k)$, we also need to estimate the variance component σ_ε^2. However, when the disturbances are nonstationary, σ_ε^2 cannot be estimated using the procedure suggested by Baltagi and Li (1991) and should be estimated as follows:

$$\widehat{\sigma}_\varepsilon^2 = \frac{1}{N(T-1)} \sum_{i=1}^N \sum_{t=2}^T (u_{it} - u_{it-1})^2.$$

The estimate of the change point, k, is defined as

$$\widehat{k} = \arg\max_k \mathrm{W}_1(k) = \arg\max_k \mathrm{W}_2(k).$$

We consider the following panels of countries: (1) OPEC countries; (2) industrialized countries; (3) panels based on geographic location, i.e., (*i*) Africa, (*ii*) U.S. and Canada, (*iii*) South and Central America, (*iv*) Asia, (*v*) Europe, and (*vi*) Australia; and (4) the world. For each of the panels of counties, we not only analyze growth rates of real per capita GDP, but also growth rates of real per capita consumption and real GDP per worker. This will allow a comparison of how slowdowns in GDP growth relate to slowdowns in productivity growth and consumption growth. The analysis is carried out as follows. We begin by assuming that the data is trend stationary (results for the case when the data is assumed to be $I(1)$ are available upon request, however, the results are not substantially affected). Next, we test for common break points in each panel using the tests developed by Emerson and Kao (2001). Table 1 summarizes the tests for structural change and reports the estimated break year. Finally, the growth rates are estimated using the fixed effects (FE) estimator (again the results using the FD estimator are available upon request). Kao and Emerson (2004) have shown that the FE estimator is as efficient as the GLS estimator when the error term is $I(0)$ and the FD estimator is as efficient as the GLS estimator when the error term is $I(1)$. In addition to the growth rates for the entire time period, the prebreak and postbreak growth rates are also estimated. The estimated growth rates for each panel of countries are reported in Table 2.

The first panel of countries that is considered is a panel of OPEC countries, excluding Kuwait, Libya, Qatar, and United Arab Emirates, for the period 1960-1987. According to the Economic Report of the President, the Organization of Petroleum Exporting Countries consists of Algeria, Ecuador (through 1992), Gabon (through 1994), Indonesia, Iran, Iraq, Kuwait, Libya, Nigeria, Qatar, Saudi Arabia, United Arab Emirates, and Venezuela. The countries of Kuwait, Libya, and United Arab Emirates were omitted from the panel due to insufficient data on these countries. Focusing on the results for real GDP per capita, we see that each of the test statistics leads to a rejection of the hypothesis of no structural change at the 1% level, except T_1. However, the OLS prebreak and postbreak GDP growth rates are 4.28% and -2.46%, respectively. There appears to be a very severe slowdown (meltdown, according to Ben-David and Papell) in GDP growth in 1975 for these OPEC nations. Turning our attention to real per capita consumption, each of the statistics used to test for structural change leads to a rejection of the null hypothesis of no structural change at the 1% level, except T_1. There appears to be a very severe slowdown (meltdown) in consumption growth in 1978 for these OPEC nations. Interestingly, this slowdown in consumption growth occurred after the slowdown in GDP growth. Finally, the results of the analysis on real GDP per worker indicate that each of the statistics leads us to reject the null of no structural change at the 1% level, except T_1. However, there appears to be a very severe slowdown (meltdown) in productivity growth in 1975 for these OPEC nations. This slowdown in productivity growth occurs in the same year as the slowdown in GDP growth.

The second panel considered is a panel of industrial countries for the period 1950-1990. The Economic Report of the President classifies the following as industrial countries: United States, Canada, Australia, Japan, New Zealand, Austria, Belgium, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, United Kingdom, South Africa, and Luxembourg. We begin by considering real per capita GDP for this panel of industrial countries. It appears industrial countries experienced a moderate slowdown in GDP growth in 1971. We next consider growth in real per capita consumption and find that there appears to have been a moderate slowdown in consumption growth in 1972 for this panel of industrial countries. This slowdown in consumption growth occurred at or just after the slowdown in GDP growth. Finally, we find that this panel of industrial countries experienced a moderate slowdown in productivity growth in 1971, which corresponds to the slowdown in GDP growth.

In addition to investigating OPEC countries and industrial countries, we also consider panels of countries grouped according to geography. Specifically, we consider the following panels of countries: Africa, United States and Canada, Central and South America (Ben-David and Papell call this group "Latin America"), Asia, Europe, and Australia.

The first grouping considered is the panel of African countries for the period 1970-1986. There appears to have been a severe slowdown (meltdown) in GDP growth and productivity growth in 1978, and a severe slowdown (meltdown) in consumption growth in 1979 for this panel of African countries. Again, we see that the slowdown in productivity growth corresponds to the slowdown in GDP growth but the slowdown in consumption growth occurs after the slowdown in GDP and productivity growth.

The second grouping considered is the panel consisting of the United States and Canada for the period 1950-1992. We find moderate evidence for a slowdown in GDP growth in 1976, a slowdown in consumption growth in 1975, and a slowdown in productivity growth in 1970. This is at odds with the results of Ben-David and Papell, who did not find evidence of slowdowns in growth for the United States and Canada. Further investigation suggests that GDP, consumption, and productivity are not trend stationary. If we use the tests for structural change for the $I(1)$ case, our results change drastically. For the GDP series and the consumption series we can only reject the null hypothesis of no structural change at the 10% level using $expW_2$. For the production series we cannot reject the null hypothesis of no structural change. The results treating each series as $I(1)$ agrees with the results of Ben-David and Papell.

The third grouping considered is the panel of Central and South American countries for the period 1960-1989. This is the group of countries that Ben-David and Papell refer to as Latin America. We find evidence of very severe slowdowns (meltdowns) in GDP growth, consumption growth, and productivity growth. The meltdowns in GDP growth and consumption growth occur in 1976 while the meltdown in productivity growth occurs in 1975. This result also mirrors the analysis of Ben-David and Papell.

The fourth grouping considered is the panel of Asian countries for the period 1969-1986. Again, we find evidence of severe slowdowns in GDP growth, consumption growth, and productivity growth. The slowdowns in GDP growth and productivity growth occur in 1978 while the slowdown in consumption growth occurs in 1979.

The fifth grouping considered is the panel of European countries for the period 1970-1989. We find some evidence of moderate to severe slowdowns in GDP growth, consumption growth, and productivity growth. The slowdowns in GDP growth, consumption growth, and productivity growth each occur in 1977.

The final geographical grouping considered is the panel of Australian countries for the period 1960-1990. It appears that fairly severe slowdowns in GDP growth and productivity growth occur in 1974 for these Australian countries. There also seems to be some evidence of a fairly severe slowdown in consumption growth in 1975.

Finally, for comparison, we consider a panel of all of the countries we have considered for the period 1970-1986. In other words, we look for a common worldwide slowdown in growth. Each of the test statistics leads to a rejection of the null hypothesis of no structural change at the 5% level for each series. There appears to have been a severe slowdown in GDP growth, consumption growth, and productivity growth in 1978 for the panel consisting of all countries in the study.

The asymptotic critical values of T_1, T_2, $supW_1$, $meanW_1$, $expW_1$, $supW_2$, $meanW_2$, and $expW_2$ are reported in Table 3. We also report the finite sample critical values for each of the test statistics in Tables 4, 5, and 6.

Remark 1 *It is important to note that the finite sample critical values are sensitive to the value of* ρ. *Finite sample critical values tend to decrease as* ρ *increases, when the data is trend stationary. Alternatively, finite sample critical values tend to increase as* ρ *increases, when the data is* $I(1)$. *Therefore, the simulated finite sample critical values reported for* T_1, $supW_1$, $meanW_1$, *and* $expW_1$ *correspond to* $\rho = 0$, *while the simulated finite sample critical values reported for* T_2, $supW_2$, $meanW_2$, *and* $expW_2$ *correspond to* $\rho = 1$. *Also, for the sample sizes considered here, the finite sample critical values do not vary significantly for different cross-section dimensions.*

Remark 2 *We follow the panel literature to assume that the countries within each group have a common slope (growth rate),* β, *and a common error structure, i.e. common value of the parameter* ρ.

5. Concluding Remarks

This paper uses the results of Kao and Emerson (2004) and Emerson and Kao (2001, 2002) to estimate the annual growth rates of real per capita GDP, real per capita consumption, and real GDP per worker and to test for structural changes in these growth rates for many different panels of countries. This paper extends the analysis of Ben-David and Papell by looking for structural changes in consumption growth and productivity growth in addition to GDP growth for different panels of countries. The results of this panel data analysis are very similar to the analysis of Ben-David and Papell. We also find that there appears to have been a worldwide slowdown in GDP growth, consumption growth, and productivity growth. Further, the timing of the slowdowns agrees with previous analysis. We find that industrial countries experienced slowdowns in growth in the early 1970s, whereas less developed countries (for example, Latin American countries, African countries, and OPEC countries) also experienced slowdowns in growth, but the timing of the slowdowns is in the mid to late 1970s. Interestingly, we also find that there was not a significant slowdown in GDP growth, consumption growth, or productivity growth for the panel of the United States and Canada. We also compare the relationships between the structural changes in the growth rates for the three series, GDP, consumption, and productivity. We find that when there are significant structural changes in the growth rates, the slowdowns in GDP and productivity growth occur at about the same time within a certain panel. Also, a slowdown in consumption growth tends to lag behind the slowdowns in productivity and GDP growth.

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Table 1: Tests for Structural Change

Table 1A: GDP per capita

Panel of Countries	T_1	$sup\mathrm{W}_1$	$Mean\mathrm{W}_1$	$Exp\mathrm{W}_1$	estimated break year
OPEC	0.2144	27.529	7.597	11.302	1975
Industrial	0.5936	1416.175	361.933	704.571	1971
Africa	0.4637	121.920	37.080	58.130	1978
USA and Canada	0.1300	97.1239	35.5764	45.7912	1976
Central and South America	0.5133	311.2676	93.5692	152.4209	1976
Asia	0.2449	53.090	16.220	23.730	1978
Europe	0.3877	643.140	186.660	318.680	1977
Australia	0.1118	43.752	12.358	19.0143	1974
World	0.7681	535.00	157.00	265.00	1978

Table 1B: Consumption per capita

Panel of Countries	T_1	$sup\mathrm{W}_1$	$Mean\mathrm{W}_1$	$Exp\mathrm{W}_1$	estimated break year
OPEC	0.1935	13.881	3.476	4.7638	1978
Industrial	0.5599	1132.186	269.287	562.379	1972
Africa	0.4512	59.910	17.380	27.430	1979
USA and Canada	0.1654	268.4042	73.8943	130.3422	1975
Central and South America	0.4927	161.7311	49.8222	77.5303	1976
Asia	0.2435	30.900	9.930	13.050	1979
Europe	0.4099	561.000	155.000	277.000	1977
Australia	0.1865	62.910	14.350	28.400	1975
World	0.7681	307.000	90.000	151.000	1978

Table 1C: GDP per worker

Panel of Countries	T_1	$sup\mathrm{W}_1$	$Mean\mathrm{W}_1$	$Exp\mathrm{W}_1$	estimated break year
OPEC	0.1652	16.1030	4.5990	5.7935	1975
Industrial	0.6369	1668.669	467.124	10000	1971
Africa	0.4410	112.000	35.000	53.000	1978
USA and Canada	0.3592	790.6584	173.6228	391.6172	1970
Central and South America	0.5225	319.2610	102.4508	156.7541	1975
Asia	0.2624	62.000	19.000	28.000	1978
Europe	0.3770	572.000	166.000	283.000	1977
Australia	0.3713	512.000	144.000	253.000	1974
World	0.7834	571.000	169.000	283.000	1978

Table 2: Growth Rate Estimates

Table 2A: GDP per capita

Panel of Countries	FE	FE pre-break	FE post-break
OPEC	0.0255	0.0428	-0.0246
Industrial	0.0305	0.0367	0.0191
Africa	0.0060	0.0159	-0.0088
USA and Canada	0.0226	0.0238	0.0161
Central and South America	0.0149	0.0270	-0.0092
Asia	0.0319	0.0406	0.0157
Europe	0.0242	0.0354	0.0198
Australia	0.0141	0.0283	0.0039
World	0.0149	0.0259	-0.0003

Table 2B: Consumption per capita

Panel of Countries	FE	FE pre-break	FE post-break
OPEC	0.0325	0.0377	-0.0177
Industrial	0.0297	0.0344	0.0189
Africa	0.0043	0.0108	-0.0098
USA and Canada	0.0241	0.0250	0.0173
Central and South America	0.0127	0.0240	-0.0125
Asia	0.0354	0.0412	0.0186
Europe	0.0238	0.0356	0.0196
Australia	0.0161	0.0251	0.0059
World	0.0148	0.0240	0.0007

Table 2C: GDP per worker

Panel of Countries	FE	FE pre-break	FE post-break
OPEC	0.0267	0.0467	-0.0254
Industrial	0.0285	0.0384	0.0144
Africa	0.0104	0.0189	-0.0024
USA and Canada	0.0162	0.0206	0.0114
Central and South America	0.0126	0.0282	-0.0115
Asia	0.0295	0.0386	0.0126
Europe	0.0209	0.0320	0.0166
Australia	0.0103	0.0250	0.0006
World	0.0142	0.0247	-0.0002

Table 3: Asymptotic Critical Values of the Tests

	T_1	T_2	$sup\mathrm{W}_1$	$Mean\mathrm{W}_1$	$Exp\mathrm{W}_1$	$sup\mathrm{W}_2$	$Mean\mathrm{W}_2$	$Exp\mathrm{W}_2$
1%	0.940	0.108	4.308	0.900	0.443	0.060	0.018	-0.344
5%	0.784	0.083	3.140	0.584	0.135	0.036	0.011	-0.349
10%	0.708	0.071	2.640	0.463	0.026	0.027	0.008	-0.351

Table 4: Simulated Critical Values For T=10 (14 for Wald-type statistics)

	T_1	T_2	$sup\mathrm{W}_1$	$Mean\mathrm{W}_1$	$Exp\mathrm{W}_1$	$sup\mathrm{W}_2$	$Mean\mathrm{W}_2$	$Exp\mathrm{W}_2$
1%	0.802	0.112	3.582	0.958	0.542	0.056	0.017	-0.236
5%	0.657	0.087	2.553	0.624	0.244	0.037	0.011	-0.234
10%	0.580	0.074	2.038	0.503	0.132	0.028	0.008	-0.230

Table 5: Simulated Critical Values For T=25

	T_1	T_2	$sup\mathrm{W}_1$	$Mean\mathrm{W}_1$	$Exp\mathrm{W}_1$	$sup\mathrm{W}_2$	$Mean\mathrm{W}_2$	$Exp\mathrm{W}_2$
1%	0.847	0.108	3.741	0.938	0.493	0.059	0.019	-0.211
5%	0.695	0.084	2.693	0.614	0.239	0.036	0.011	-0.216
10%	0.614	0.073	2.212	0.498	0.142	0.027	0.008	-0.218

Table 6: Simulated Critical Values For T=50

	T_1	T_2	$sup\mathrm{W}_1$	$Mean\mathrm{W}_1$	$Exp\mathrm{W}_1$	$sup\mathrm{W}_2$	$Mean\mathrm{W}_2$	$Exp\mathrm{W}_2$
1%	0.882	0.108	3.912	0.943	0.476	0.061	0.018	-0.296
5%	0.724	0.086	2.787	0.614	0.186	0.037	0.011	-0.294
10%	0.646	0.073	2.299	0.482	0.076	0.028	0.008	-0.289