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THE GREAT WARS, THE GREAT CRASH, AND THE UNIT ROOT HYPOTHESIS: SOME NEW EVIDENCE ABOUT AN OLD STYLIZED FACT

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ABSTRACT

For decades, the prevailing sentiment among economists was that growth rates remain constant over the long run. Kaldor considered this to be one of the six important "stylized facts" that theory should address, and until the emergence of endogenous growth models, this was a fundamental feature of growth theory.

This paper uses an endogenous trend break model to investigate the unit root hypothesis for 16 countries, using annual GDP data spanning up to 130 years. Rejection of the unit root, which is facilitated by the inclusion of a trend break, introduces the possibility of examining the long run behavior of growth rates.

We find that most countries exhibited fairly steady growth for a period lasting several decades. The termination of this period was usually characterized by a significant, and sudden, drop in GDP levels. But rather than simply returning to their previous steady state path, as predicted by the standard neoclassical growth model, most countries continued to grow at roughly *double* their prebreak rates for many decades, even after their original growth path had been surpassed.

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I. INTRODUCTION

One of the fundamental "stylized facts" that characterized postwar growth literature is that output grows "at a steady trend rate", both in aggregate and per worker terms (Kaldor, 1961). This feature is one of the prominent characteristics of the Solow (1956) neoclassical growth model. Three decades later, the endogenous growth literature, starting with Romer (1986), has shown that growth rates need not be constant and they may actually increase over time.

Empirical research on this issue has not provided a clear choice between the endogenous and neoclassical growth models. Romer (1986 and 1989) provides evidence that growth rates have been rising over time. Using data from Maddison (1982), he shows that rates of growth for countries that were productivity leaders have risen since 1700. In an analysis of the United States, Romer (1986) calculates 40 year annual averages and finds increases in the rates of growth between 1840 and 1978. Abramovitz (1989), however, uses moving average computations to smooth business fluctuations and concludes that U.S. aggregate and per capita growth rates exhibited a slowdown between 1870 and 1953. In contrast, Romer (1986), using one observation per decade, rejects the hypothesis that there is a non-positive trend in the growth rate over successive decades for eight of eleven countries. He then shows how, within a fully specified equilibrium, per capita output may grow without bound at rates that can be increasing over time.

The analysis here differs from the Romer and Abramovitz studies in that it does not use broad averages based on arbitrary period lengths to determine the long run behavior of growth rates. Recent breakthroughs in time series analysis enable an endogenous determination of trend breaks within the framework of unit root tests. Rejection of the unit root null permits the calculation of steady state growth rates.

Our empirical work builds upon much previous research which examines whether real GNP (or GDP) can be characterized by a unit root. Following Nelson and Plosser's (1982) failure to reject the unit root null for either aggregate or per capita U.S. GNP, Perron (1989), with the break date determined exogenously, and Zivot and Andrews (1992), with an endogenous break choice, find that the unit root hypothesis can be rejected if a one-time break is incorporated in the deterministic trend. While the above studies focus on the U.S., Raj (1992) and Perron (1993) use endogenous trend break tests and extend the unit root analysis to additional countries.[1]

In this paper, we utilize up to 130 years of annual aggregate and per capita GDP data for 16 countries to investigate whether economic growth is constant or changing over time. For nearly every one of the countries, the trend break which provides the strongest evidence against the unit root null is associated with a sharp decline in GDP: World War II for most countries, World War I or the Great Depression for the rest.

This study provides empirical evidence that while countries do tend to exhibit relatively constant growth rates for extended periods of time, the occurrence of a major shock to the economy appears to result in a drop in levels followed by sustained growth that exceeds the earlier steady state growth. In 20 of the 32 cases examined (16 aggregate and 16 per capita), countries exhibit significant steady state behavior, growing at constant rates until a major

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[1] Neither Raj (1992) nor Perron (1993) considers issues of economic growth. In the unit root context, this paper extends their work by examining more countries over a longer time span.

upheaval occurs. Postbreak growth of aggregate GDP for stationary countries was twice the prebreak growth. In the case of per capita GDP, postbreak growth rates were, on average, two and a half time the prebreak rates.[2]

The finding that posthreak exceed prebreak growth rates is not sufficient to distinguish between the neoclassical and endogenous growth models. While both frameworks would predict this outcome during the transition phase back to the steady state path, the neoclassical model also predicts that, once the steady state is reached, growth rates should return to their prebreak steady state values. Our results show that the faster growth usually continues even after the countries reach, and eventually surpass, their previous steady state paths, with the new, post-transition, rates of growth greatly exceeding the old steady state rates.

This result suggests a possible bridge between the Romer-type increasing growth predictions and the Olson (1982) explanation that major social upheavals can cause a breakup of coalitions whose long-term existence may have lead to a petrification of resource allocations within an economy. The ensuing removal of these rigidities can lead to a more efficient allocation of resources and hence, to faster subsequent growth. We find the existence of a significant relationship between the magnitude of the decline in GDP levels and the subsequent increase in post-transition period growth rates over prebreak steady state rates.[3]

The paper is organized as follows. Sequential Dickey-Fuller tests for unit roots are summarized and empirical results are presented in Section II. Implications of these results for

[2] Growth behavior in the non-significant cases did not appear to be appreciably different.

[3] Our finding of increased growth rates raises the possibility, discussed by Romer (1986), that they are continuously changing. We investigate the possibility of higher order nonstationarity by testing for unit roots in GDP growth rates. Using Augmented-Dickey-Fuller tests (without breaks), the unit root null can be rejected at the 1 percent level for both aggregate and per capita real GDP growth for all 16 countries.

issues involving economic growth are considered in Section III. Conclusions are presented in Section IV.

II. Trend Breaks and Unit Roots

The question of whether macroeconomic variables, in particular real GNP, can be characterized by unit roots has been the subject of considerable investigation.[4] Nelson and Plosser (1982), in a widely cited study using long-term annual data for the United States, showed that the null hypothesis of a unit root could not be rejected for most macroeconomic variables.[5]

These results have not gone unchallenged. Perron (1989) argues that only two events, the Great Crash of 1929 and the oil price shock of 1973, have had a permanent effect on macroeconomic variables. Using the same data as Nelson and Plosser, he shows that, allowing a single change in either the intercept of the trend function after 1929 or the slope of the trend function after 1973, most macroeconomic variables, including aggregate and per capita GNP, are trend stationary.[6]

Perron's results have also not gone unchallenged. In Perron (1989), the date of the break is treated as known. Christiano (1992) argues that the date of the break should be treated as unknown *a priori*. He uses bootstrap methods to compute appropriate critical values, and shows

[4] Campbell and Perron (1991) provide extensive references.

[5] The exception was the unemployment rate.

[6] Rappoport and Reichlin (1989) also develop unit root tests with trend breaks.

that there is little evidence in favor of the hypothesis that postwar U.S. real GNP is stationary around a broken trend against the unit root null.[7]

This study uses an endogenous trend break model to investigate the unit root hypothesis for both aggregate and per capita GDP. Two issues, both emphasized by Campbell and Perron (1991), guide our choices of data and tests. First, the power of unit root tests is largest when the span of the data is longest. Second, lengthening the span of the data increases the possibility of a major structural change. We utilize a much longer time span (130 and 120 years for most of the aggregate and per capita data, respectively) and include more countries (sixteen) than is common in unit root studies.

The sequential Dickey-Fuller tests of Zivot and Andrews (1992) are run on data compiled by Maddison (1991).[8] He provides annual GDP data for 16 countries, mostly starting in 1860 for aggregate and 1870 for per capita data and ending in 1989. Indexes of annual aggregate real GDP (adjusted to exclude the impact of boundary changes) were converted into 1985 U.S. relative prices using OECD purchasing power parity units of national currency per U.S. dollar. Annual per capita GDPs were calculated by dividing the aggregate GDPs by the mid-year

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[7] Banerjee, Lumsdaine, and Stock (1992) use a variety of tests based on asymptotic distribution theory, which also treat the break date as unknown *a priori*, to investigate these questions. Using postwar GNP for the G-7 countries, they can only reject the unit root null in favor of the trend shift hypothesis for Japan. Zivot and Andrews (1992), using a sequential Dickey-Fuller test on both long-run and postwar Nelson-Plosser data, find less evidence against the unit root hypothesis than was found by Perron (1989).

[8] These tests are univariate. Bai, Lumsdaine, and Stock (1991) develop multivariate tests for dating breaks, but do not test for unit roots.

population levels.[9] While the annual aggregate data begins in 1860 for most countries, the per capita GDP is limited by the population data which begins in 1870.

It should be pointed out that data for the war years tends to be considerably less accurate than for the remaining years. Thus, one should not attach too much importance to a break that occurs during one war year rather than another. The emphasis here will be on the fact that the break is related to a war rather than to a precise year.

These concerns are particularly important in the case of Germany, which underwent several wars that coincided with substantial population and territorial changes over the past century. Maddison (1991) makes an important contribution in trying to correct for these changes, but nonetheless, a note of caution is warranted regarding the accuracy of the German results.

To provide a benchmark for our later results, we compute Augmented Dickey-Fuller (ADF) tests which do not incorporate breaks (the results appear in the Appendix). For 15 of the 16 countries, the null hypothesis of a unit root cannot be rejected at the 10 percent level for either aggregate or per capita real GDP. These findings support Nelson and Plosser's (1982) inability to reject the unit root null, despite our utilization of much longer spans of data. Surprisingly, the lone exception is the United States (which was the basis of the Nelson and

[9] The Maddison data were modified for consistency purposes. For example, the regions of Alsace and Lorraine were included in the French total and deducted from the German total population count. The U.K. figures were adjusted so as not to include Irish GDP or population. Also, the Italian population statistic for 1870 was augmented by Rome's population so as to accord with the subsequent Italian population data. These changes were relatively minor and did not affect the ADF regressions in any meaningful way.

Plosser study), where the null can be rejected at the 5, but not the 1, percent level for both variables.

A plausible reason for the failure of our ADF tests to reject the unit root null is misspecification of the deterministic components included as regressors.[10] With long spans of data, it becomes more likely that the series of interest is characterized by a major structural change. Failure to account for such a structural change biases the test in favor of the unit root hypothesis.

Augmented-Dickey-Fuller tests which incorporate breaks involve regressions of the following form,

$$(1) \qquad \Delta y_t = \mu + \theta DU_t + \beta t + \gamma DT_t + \alpha y_{t-1} + \sum_{j=1}^{k} c_j \Delta y_{t-j} + \varepsilon_t \,.$$

The period at which the change in the parameters of the trend function occurs will be referred to as the time of break, or T_B. The break dummy variables have the following values: $DU_t = 1$ if $t > T_B$, 0 otherwise, and $DT_t = t$ if $t > T_B$, 0 otherwise.[11] Following Zivot and Andrews (1992), models are estimated for $T_B = 2,\ldots,T\text{-}1$, where T is the number of observations after adjusting for those "lost" by first-differencing and lag length k.

For each choice of T_B, the value of k is selected by the criteria advocated by Campbell and Perron (1991), which is described in the Appendix. The time of break for each series is selected by choosing the value of T_B for which the Dickey-Fuller t-statistic is maximized. The

[10] The sensitivity of unit root tests to specification of trends underlying postwar U.S. GNP is investigated by Bhargava (1990).

[11] Zivot and Andrews define $DT_t = t - T_B$. This makes no difference for the Dickey-Fuller t-statistic but we choose $DT_t = t$ to facilitate the growth analysis in the next section.

null hypothesis, that the series $\{y_t\}$ is an integrated process without an exogenous structural break, is tested against the alternative hypothesis that $\{y_t\}$ is trend stationary with a one-time break in the trend function which occurs at an unknown time.[12]

Following Perron's nomenclature, there are three possible models under the alternative hypothesis. Model A, the "crash" model, allows for a change in the intercept of the trend function (this will be referred to as a level change), *DU*, but not in the slope. Model B, the "changing growth" model, allows for a change in the slope of the trend function (to be referred to as a trend change), *DT*, but not in the intercept. Model C allows for both level and trend changes. We first estimate regressions for Model C under the alternative. If the *t*-statistics on *DU* and *DT* are both significant for the chosen TB_t, we report the results for Model C. If either *t*-statistic is insignificant, we drop the associated variable and estimate either Model A or B.[13]

Our major results are summarized in Table 1 and the full set of coefficients and associated *t*-statistics are presented in Table A2 (panels A and B). For the vast majority of countries, both the intercept and slope trend break dummy variables are significant, making Model C the appropriate model. Model A is estimated for Switzerland and Model B for Germany.[14] For the United States, Model A is estimated for aggregate real GDP but Model C is estimated for per capita real GDP. This differs from both Perron (1989) and Zivot and

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[12] Our specification is identical to Zivot and Andrews (1992). Perron (1989, 1993) takes the time of break to be exogenous under the null, which requires estimating an additional dummy variable $DTB_t = 1$ if $t = T_B + 1$, 0 otherwise. We estimated our models with this additional variable. The results were essentially unchanged, except that, as in Perron (1993), most of the break dates were one year earlier.

[13] There were no cases where both *t*-statistics were insignificant for Model C. When Models A or B were estimated, the *t*-statistics for *DU* and *DT*, respectively, were always significant. Since the choice among models does not depend on the Dickey-Fuller *t*-statistic, this selection procedure will not affect the critical values.

[14] Following Perron (1993), we estimate Model B as a two-step procedure and the coefficients for Germany in Table A2 reflect this.

Table 1 **Sequential Unit Root Tests: Main Results**

Aggregate Real GDP (through 1989)

Country	First Year of Sample	Year of Break	Dickey-Fuller t-statistic ($t_{\hat{\alpha}}$)	k	Model
Australia	1860	1925	4.15	8	C
Austria	1870	1944	4.86 *	2	C
Belgium	1860	1939	5.77 ***	3	C
Canada	1870	1928	5.97 ***	7	C
Denmark	1860	1939	4.21	3	C
Finland	1860	1913	6.01 ***	3	C
France	1860	1939	6.60 ***	8	C
Germany	1860	1956	5.40 ***	1	B
Italy	1861	1940	4.16	1	C
Japan	1885	1944	6.31 ***	8	C
Netherlands	1900	1939	4.23	7	C
Norway	1865	1944	3.55	0	C
Sweden	1860	1913	4.24	5	C
Switzerland	1899	1944	3.84	0	A
U.K.	1860	1918	6.61 ***	5	C
U.S.A.	1869	1929	5.71 ***	7	A

Per Capita Real GDP (through 1989)

Country	First Year of Sample	Year of Break	Dickey-Fuller t-statistic ($t_{\hat{\alpha}}$)	k	Model
Australia	1870	1927	4.61	8	C
Austria	1870	1944	5.99 ***	5	C
Belgium	1870	1939	6.26 ***	3	C
Canada	1870	1928	6.41 ***	7	C
Denmark	1870	1939	5.84 ***	4	C
Finland	1870	1913	4.82 *	4	C
France	1870	1939	6.06 ***	8	C
Germany	1870	1955	4.57 **	0	B
Italy	1870	1939	4.36	1	C
Japan	1885	1944	6.57 ***	8	C
Netherlands	1900	1939	4.24	7	C
Norway	1870	1939	3.62	3	C
Sweden	1870	1916	5.55 **	4	C
Switzerland	1899	1944	4.37	0	A
U.K.	1870	1918	5.42 **	8	C
U.S.A.	1870	1929	5.95 ***	8	C

Critical Values for $t_{\hat{\alpha}}$

Model	Significance Levels			
	10% *	5% **	2.5%	1% ***
A	4.58	4.80	5.02	5.34
B	4.11	4.42	4.67	4.93
C	4.82	5.08	5.30	5.57

Source: Zivot and Andrews (1992)

Andrews (1992), neither of which allows for a change in the slope of the trend function and thus estimates Model A by assumption.[15]

The dates of the breaks accord closely with intuition. The countries which exhibit significant breaks during the Second World War; Japan, Norway, and the continental European countries (Austria, Belgium, Denmark, France, Germany, Italy, the Netherlands, and Switzerland), are those which were most affected by the War.[16] Breaks occur during the First World War for the United Kingdom (where the trauma of the War was followed by the loss of Ireland and the outbreak of an extremely deadly and widespread flu epidemic), Finland (which achieved independence from Russia), and Sweden.

The countries that were most removed physically and suffered the least damage during both World Wars; Australia, Canada, and the United States, exhibit breaks between 1925 and 1929. The results of Zivot and Andrews (1992) concerning real GNP for the United States continue to hold with our longer span of data. We find the time of break to be 1929 for both aggregate and per capita real GDP, exactly what was assumed by Perron and found by Zivot and Andrews. This result, based on a span of data about twice as long as the Nelson-Plosser data, provides further evidence for the Great Crash as the cause of the U.S. break.[17]

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[15] We also ran sequential ADF tests on the long-term GNP data analyzed in Backus and Kehoe (1992), which we thank David Backus for providing. For the six countries; Australia, Canada, Italy, Sweden, the United Kingdom, and the United States, for which the Backus-Kehoe data did not contain gaps, the choice of models, selection of break dates, and significance levels of Dickey-Fuller t-statistics was similar to the Maddison data.

[16] Norway was invaded by Germany in 1940.

[17] It is interesting to compare our results for the United States with those of Zivot and Andrews (1992). For aggregate real GDP, we choose Model A with lag length $k = 7$ and reject the unit root null at the 1 percent level. These results accord exactly with those of Zivot and Andrews. For per capita real GDP, we choose Model C with lag length $k = 8$, while Zivot and Andrews assume Model A. We reject the unit root null for per capita GDP at the 1 percent level while Zivot and Andrews can only reject it at the 10 percent level. Thus, using a longer span of data, we find as much evidence against the unit root hypothesis for aggregate, and considerably more for per capita, real GDP than was found by Zivot and Andrews.

The Great Crash, however, did not cause the break for any other country. For the vast majority of countries, 13 out of 16, the breaks were caused by wars. Even for Australia and Canada, where the breaks were associated with the onset of the Great Depression, they occur before 1929. The Dickey-Fuller t-statistics associated with all possible break years are plotted for per capita real GDP in Figure 1 for Germany, Japan, the United Kingdom, and the United States.[18] The break year was the same for both aggregate and per capita GDP for 11 of the 16 countries.

The central result of this section is that allowing for breaks produces considerable evidence against the unit root hypothesis for both aggregate and per capita real GDP. We can reject the unit root null at the 1 percent level in 16 out of 32 cases, 8 each for aggregate and per capita. This contrasts with the failure of conventional ADF tests, which do not allow for breaks, to reject the unit root null at the 1 percent level in any of the 32 cases. At the 10 percent level, where conventional ADF tests reject the null in only 2 of the 32 cases, we reject the null in 20 cases, 9 for aggregate and 11 for per capita real GDP.

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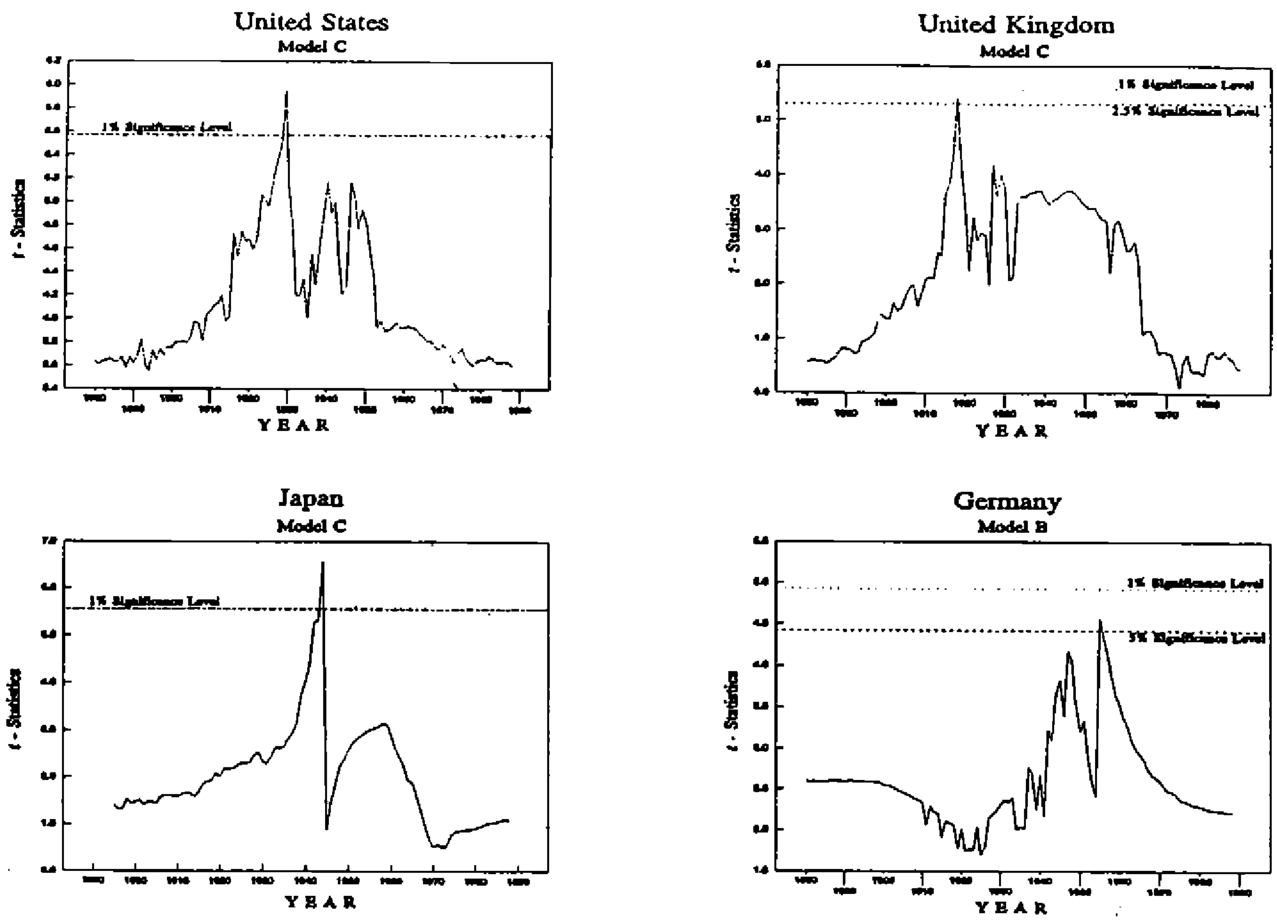
[18] These countries were selected to illustrate the range of models and break years that we find, and are not intended to be representative. Similar plots for the other countries, as well as for aggregate data, are available from the authors.

Figure 1

Dickey-Fuller t-Statistics for Per Capita GDP



III. TREND BREAKS AND STEADY STATE GROWTH

Issues involving economic growth are of great importance to both macroeconomic theory and policy. In this section, we show that countries which exhibit trend stationarity will converge to a steady state growth path. We then develop the implications of trend breaks by comparing prebreak and postbreak steady state growth rates.

Suppose that $k = 0$ (i.e. no lagged differences). Then the standard Dickey-Fuller type first-order difference equation with drift and trend is

(2) $$\Delta y_t = \mu + \beta t + \alpha y_{t-1}$$

with $y(t)$ following the time path

$$y_t = A(1+\alpha)^t - \frac{\mu\alpha+\beta(1+\alpha)}{\alpha^2} - \frac{\beta}{\alpha}t$$

where

$$A = y_0 + \frac{\mu\alpha+\beta(1+\alpha)}{\alpha^2} .$$

The annual rate of growth, Δy_t (where as before, y_t denotes the log of real GDP) is

$$\Delta y_t = A(1+\alpha)^{t-1}\alpha - \frac{\beta}{\alpha} .$$

If $y(t)$ is trend stationary, so that $-1 < \alpha < 0$, the growth rate asymptotically approaches the "steady state" constant value

(3) $$\lim_{t\to\infty} \Delta y_t = \frac{-\beta}{\alpha} .$$

From Equation 2, if *y(t)* is not trend stationary, so that $\alpha = 0$, growth rates will increase without bound, i.e.

$$\lim_{t \to \infty} \Delta y_t = \infty \quad .$$

The general form of Equation 2, which allows for k lagged differences is

(4)
$$\Delta y_t = \mu + \beta t + \alpha y_{t-1} + \sum_{j=1}^{k} c_j \Delta y_{t-j} \quad .$$

This may be rewritten as the following AR(k) process:

$$y_t = \mu + \beta t + (1+\alpha+c_1) y_{t-1} + \sum_{j=1}^{k-1} (c_{j+1} - c_j) y_{t-(j+1)} - c_k y_{t-(k+1)}$$

or, more simply

$$y_t = \mu + \beta t + \phi_1 y_{t-1} + \sum_{j=1}^{k-1} \phi_{j+1} y_{t-(j+1)} + \phi_{k+1}\, y_{t-(k+1)}$$

where

$$\phi_1 = 1+\alpha+c_1, \quad \phi_{j+1} = c_{j+1} - c_j \ , \quad \text{and} \quad \phi_{k+1} = -c_k \ .$$

As in the simple Dickey-Fuller solution (Equation 3) the rate of growth in the general $k \neq 0$ case asymptotically approaches the constant value[19]

(5)
$$\lim_{t \to \infty} \Delta y_t = \beta \ / \ (1 - \sum_{j=1}^{k} \phi_j) = \frac{-\beta}{\alpha} \quad .$$

[19] This result was verified using numerical simulations.

Thus, rejection of the unit root null implies that growth rates will stabilize around a constant value that is not dependent on k or the c's.[20] This value, $-\beta/\alpha$, will be referred to as the steady state rate of growth.

How then, does the existence of a break in the trend function affect steady state growth? A level change (i.e. a change in the intercept of Equation 1) affects income levels, but it has no effect on the growth rates. On the other hand, a trend change (i.e. a change in the slope, or trend, coefficient) in the presence of stationarity will have an impact on the country's steady state growth path.

Steady state growth rates were calculated for each country using the estimated coefficients from Table A2 for the trend ($\hat{\beta}$) and lagged GDP ($\hat{\alpha}$). The postbreak growth rates also incorporate the increment to $\hat{\beta}$ given by $\hat{\gamma}$, the coefficient for the trend dummy variable, *DT*. These steady state rates appear in Table 2. The results should be treated with caution in the cases of countries for which the null of a unit root could not be rejected (the stationary countries are marked with an asterisk). The countries are grouped according to their time of break.

The postbreak rates of growth clearly exceed the prebreak rates. With aggregate GDP, the average steady-state postbreak rate for the nine stationary countries was nearly double the prebreak rate. For all 16 countries, the postbreak rate was 78 percent above the prebreak rate. With per capita GDP, the average steady state postbreak rate was nearly two and a half times the prebreak growth rate for both the 11 stationary and for all 16 countries.

The differences were largest for those countries which experienced trend breaks during World War II, with the average ratio of postwar to prewar growth rates equal to 2.06 for

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[20] The intuition behind this is that, in augmented Dickey-Fuller tests, the rejection or non-rejection of the unit root hypothesis depends only on the value of α, not on the c's.

Table 2 **Prebreak and Postbreak Steady State Rates of Growth**

	AGGREGATE				PER CAPITA			
	Steady State Rates of Growth				Steady State Rates of Growth			
	Pre-Break (A)	Post-Break (B)	Ratio (B/A)	$\hat{\theta}$	Pre-Break (C)	Post-Break (D)	Ratio (D/C)	$\hat{\theta}$
<u>Average</u>								
All 16 Countries	2.39%	3.91%	1.78	-0.46	1.40%	3.13%	2.48	-0.53
Stationary Only	2.42%	4.13%	1.95	-0.62	1.43%	3.23%	2.49	-0.61
<u>World War II</u>								
Austria	• 1.35%	4.77%	3.52	-1.02	• 0.78%	4.37%	5.58	-1.53
Belgium	• 1.67%	3.59%	2.16	-0.51	• 0.85%	3.18%	3.72	-0.65
Denmark	2.76%	3.56%	1.29	-0.20	• 1.57%	2.83%	1.80	-0.45
France	• 1.26%	4.60%	3.64	-1.29	• 1.18%	3.73%	3.17	-0.96
Germany	• 2.21%	2.71%	1.23	0	• 1.67%	2.46%	1.47	0
Italy	1.94%	4.67%	2.40	-0.44	1.42%	4.26%	3.00	-0.44
Japan	• 3.19%	7.12%	2.23	-2.01	• 1.92%	5.98%	3.11	-1.91
Netherlands	2.88%	4.27%	1.48	-0.61	1.48%	3.10%	2.10	-0.73
Norway	2.25%	3.75%	1.67	-0.15	1.74%	3.58%	2.06	-0.27
Switzerland	1.75%	1.75%	1.00	0.09	1.53%	1.53%	1.00	0.08
Average	2.13%	4.08%	2.06	-0.61	1.41%	3.50%	2.70	-0.69
<u>World War I</u>								
Finland	• 2.76%	3.97%	1.44	-0.27	• 1.74%	3.26%	1.88	-0.23
Sweden	2.12%	3.47%	1.64	-0.17	• 1.52%	2.94%	1.94	-0.28
UK	• 1.94%	2.29%	1.18	-0.16	• 1.07%	1.93%	1.79	-0.19
Average	2.27%	3.24%	1.42	-0.20	1.44%	2.71%	1.87	-0.23
<u>Depression</u>								
Australia	2.78%	3.89%	1.40	-0.19	0.52%	2.10%	4.06	-0.33
Canada	• 4.00%	4.62%	1.16	-0.27	• 2.17%	2.74%	1.26	-0.30
US	• 3.50%	3.50%	1.00	-0.09	• 1.67%	2.09%	1.26	-0.21
Average	3.43%	4.00%	1.19	-0.18	1.45%	2.31%	2.19	-0.28

Stationary countries denoted by •

aggregate and 2.70 for per capita GDP. The average ratios of postbreak to prebreak growth were also greater than unity for the World War I and Great Depression trend break countries. As with the World War II countries, the increase in steady state growth was greater for per capita than for aggregate GDP.

The results in Table 2 appear to confirm the Romer predictions. Of the sixteen countries analyzed here over a 120 year time span, all but one displayed higher postbreak per capita growth, with steady state growth ratios exceeding unity.[21] Not one country exhibited any evidence of moving to a new path with slower growth (i.e. a sub-unity growth ratio).

While 15 of the 16 countries experienced faster per capita income growth following the break in trend, in 14 of these countries the heightened growth followed a significant drop in income *levels*. The question is, how related are these two events? Of the three groups, the WWII countries exhibited the highest steady state growth after their breaks, while the mean drop in their postbreak income levels was 2½-3 times as large, on average, as that experienced by the other two groups (Table 2). Can the higher postbreak growth be a reflection of the immensity of the negative shock experienced by the countries?

One possibility is that it takes many years to return to the stable path and the faster growth simply reflects transition back to the previous steady state path rather than to a new, higher steady state growth path. This possibility is examined below. Alternatively, this might be evidence of Mancur Olson's (1982) notion that major upheavals tend to lead to a breakup of old "distributional" coalitions. Once the major coalitions lose power, they can no longer impede

[21] The lone exception being Switzerland which experienced a positive level change at the termination of the Second World War.

a more efficient redistribution of resources. If that is the case, then one would expect faster growth to follow the major reorganizations that occurred during the periods in question.

The relationship between the mean drop in incomes and the subsequent increase in growth rates over the prebreak steady state rates may be estimated by regressing

$$DROG_i = \pi_1 + \pi_2\hat{\theta}_i + \epsilon_i \tag{6}$$

where $DROG_i$ is the relative increase in growth rates from their prebreak paths to their postbreak paths and $\hat{\theta}_i$ is the calculated drop in income for country i (both vectors are drawn from the Equation 1 estimates by country, so an income reduction is represented by a negative $\hat{\theta}_i$). The results, which appear in Table 3, reflect a significant relationship between the magnitude of the level changes induced by the break and the changes in the growth rates which followed. Much of the increase in growth rates (over the prebreak growth) can be attributed to the fall in incomes that followed the breaks.[22]

While it is clear that postbreak growth exceeded the prebreak steady state rates, there remains a question of whether these results are simply driven by the rebound of the countries during their respective transition periods. In other words, these findings may be simply a reflection of the neoclassical growth model's prediction that growth should be faster during the transition back to the steady state path. What happens when the transition periods are omitted from the postbreak results? Do GDP levels and growth rates return to their prebreak paths?

[22] Though the level changes account for approximately one half of the growth increases, it is clear that these may not be the only possible explanation for the higher postbreak growth. Germany is one example where no level changes were found to be significant though the country exhibited increases in trend. Though the country's income clearly fell at the termination of the Second World War, its rebound was so fast and so thorough that the data do not indicate any lasting level effects from the War. The country did however experience an increase in its steady state growth rates (by 23 percent for aggregate GDP and 47 percent for per capita GDP). While poor prewar data may be the source of some of these apparent changes, there are probably other factors causing the growth increase.

Table 3 **Relationship Between Pre- and Postbreak Growth Rates and Level Changes**

$$DROG_i = \pi_1 + \pi_2\hat{\theta}_i + \epsilon_i$$

	Constant	$\hat{\theta}$	NOBs	R^2
Stationary Only				
Aggregate	1.2900 (3.55)	-1.0580 (-2.60)	9	0.492
Per Capita	1.4343 (3.68)	-1.6680 (-3.62)	11	0.592
All 16 Countries				
Aggregate	1.2961 (6.58)	-1.0558 (-3.76)	16	0.503
Per Capita	1.6284 (4.90)	-1.5639 (-3.48)	16	0.464

t-statistics in parentheses

The length of each country's transition period was found by extrapolating the prebreak steady state growth path of each country from the year prior to the break. The end of the transition period is determined when the actual levels of GDP eventually equaled that of the fitted levels, *i.e.* when the country returned to its prebreak path. This left the post-transition years which could then be compared to the prebreak years.

A graphical depiction of this exercise appears in Figure 2. For completeness, the per capita GDP graphs for every one of the 16 countries is provided in this figure. In 13 of the 16 countries, there is a noticeable transition period followed by visual evidence that the post-transition behavior of GDP was clearly different from that of the prebreak years. In each of these countries, post-transition growth exceeded prebreak growth by a substantial margin. Of the three remaining countries, the United States and Canada exhibited results that conformed very closely to the neoclassical predictions of a return to the steady state path, both in terms of growth rates as well as levels. The third country, Switzerland was an outlier model A country that experienced a positive level change in its break year, 1944.

The visual evidence is corroborated by a comparison of the calculated average annual growth rates in Table 4. For those countries with transition periods, the actual growth rates exceeded the fitted steady states rates from the post-transition period by 78 percent for aggregate and 131 percent for per capita GDP. An estimation of Equation 6 with the post-transition growth *ratios* (of actual to fitted average growth rates) on the left-hand side indicates a significant relationship between the increase in growth rates and the magnitude of the drop in GDP levels (Table 5).

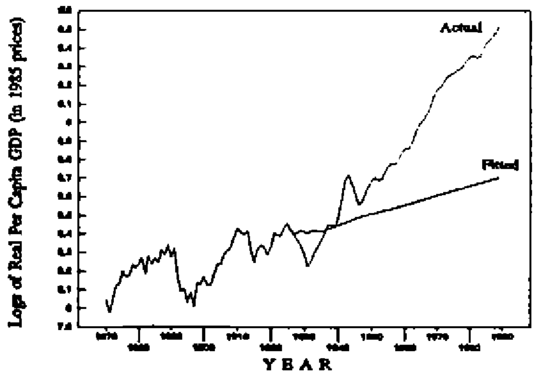
Thus the Olson explanation that big shocks are required as a precursor to heightened growth may be consistent with the Romer prediction. If, as Romer suggests, growth rates have

Figure 2.a

Post-Transition Period Comparisons
With Prebreak Growth

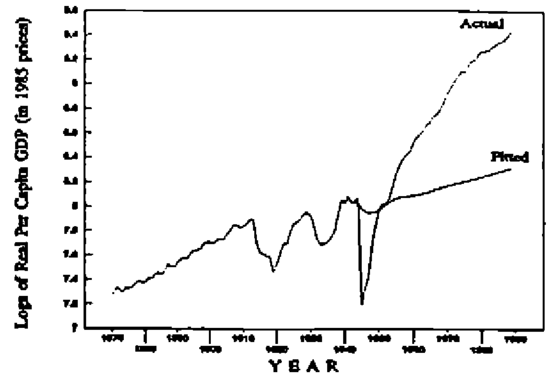
Australia, 1870-1989

Break Year: 1927, Last Year of Transition Period: 1936



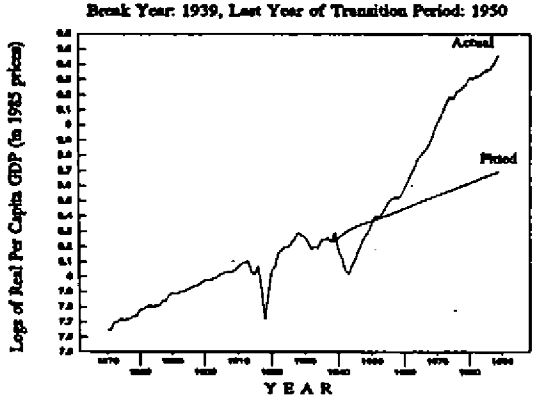
Austria, 1870-1989

Break Year: 1944, Last Year of Transition Period: 1950



Belgium, 1870-1989

Break Year: 1939, Last Year of Transition Period: 1950



Canada, 1870-1989

Break Year: 1928, Last Year of Transition Period: 1941

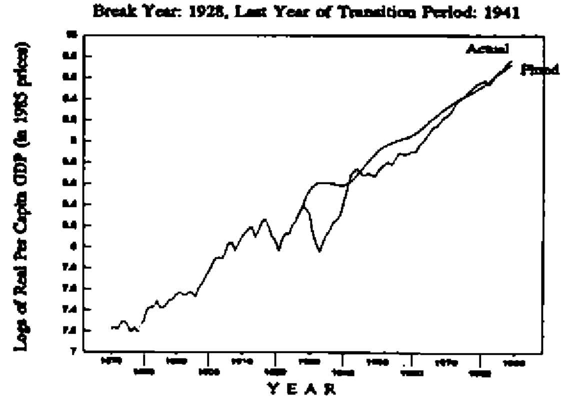


Figure 2.b

Post-Transition Period Comparisons With Prebreak Growth

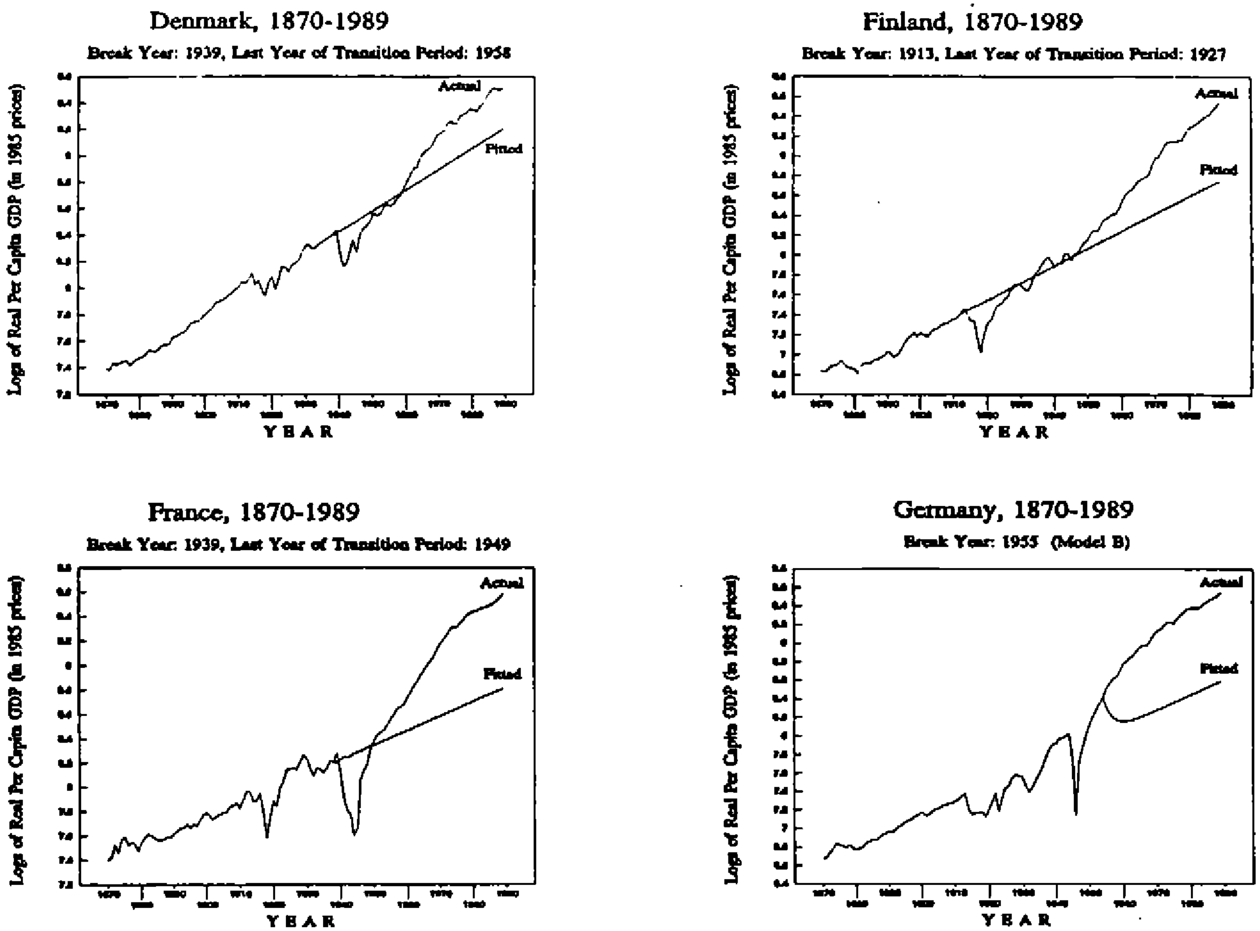
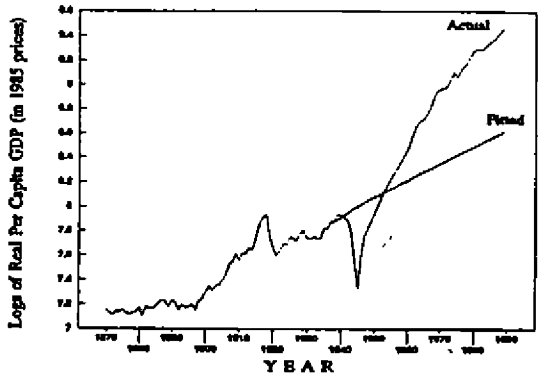


Figure 2.c

Post-Transition Period Comparisons With Prebreak Growth

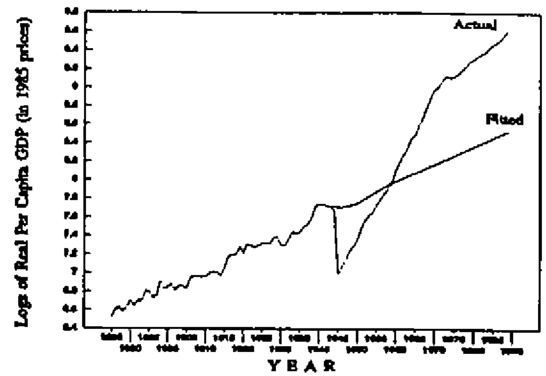
Italy, 1870-1989

Break Year: 1939, Last Year of Transition Period: 1952



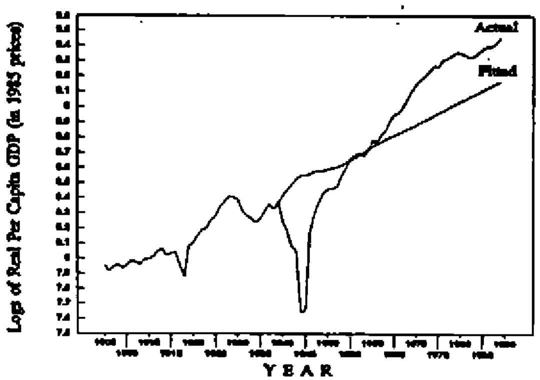
Japan, 1885-1989

Break Year: 1944, Last Year of Transition Period: 1958



Netherlands, 1900-1989

Break Year: 1939, Last Year of Transition Period: 1954



Norway, 1870-1989

Break Year: 1939, Last Year of Transition Period: 1946

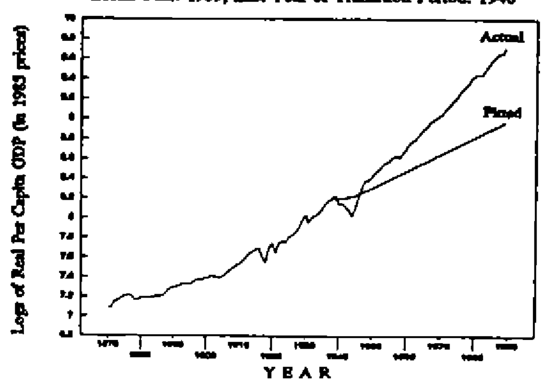


Figure 2.d

Post-Transition Period Comparisons With Prebreak Growth

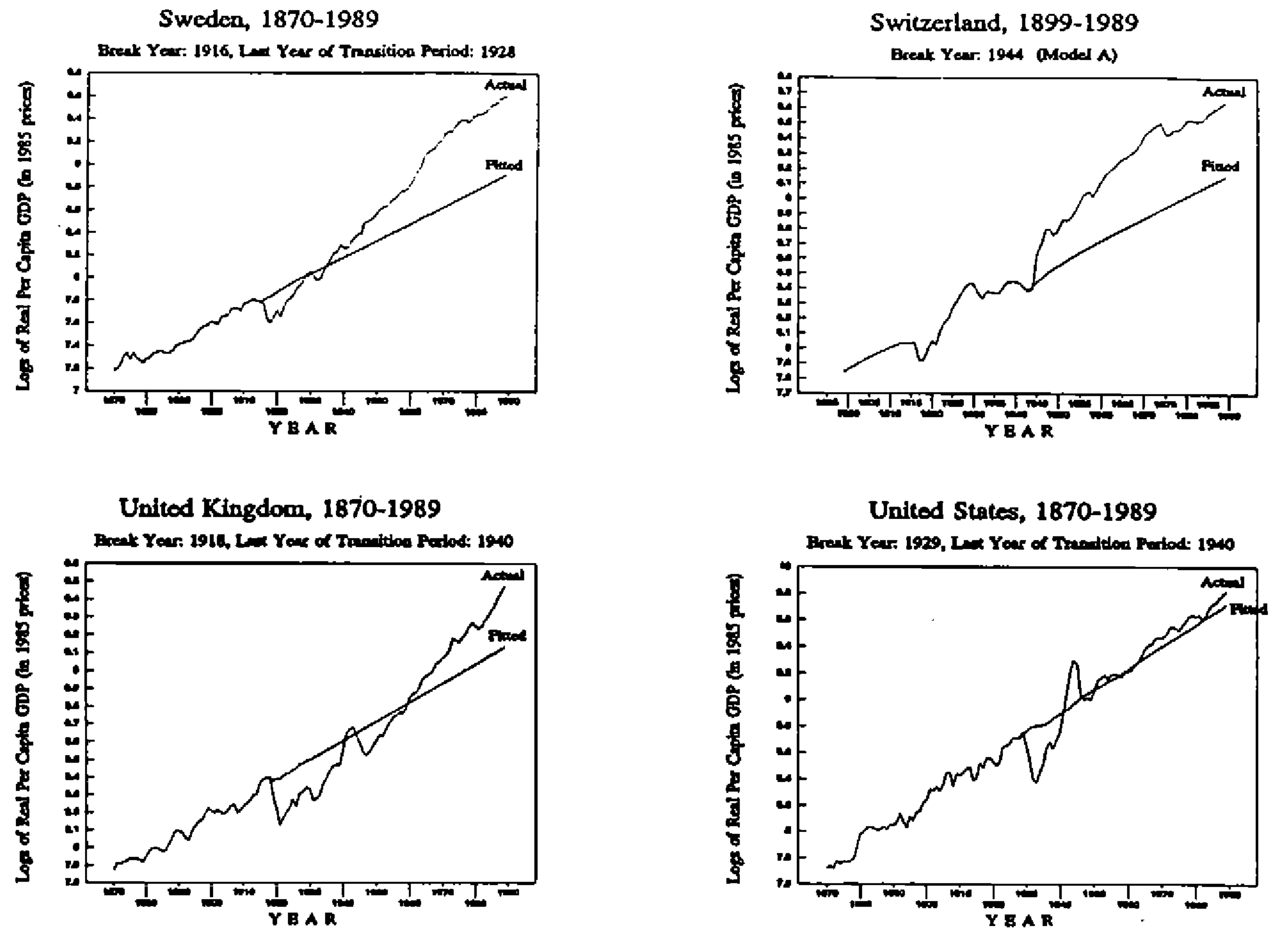


Table 4

Post-Transition
Average Annual Rates of Growth

	Aggregate			Per Capita		
	Fitted (A)	Actual (B)	Ratio (B/A)	Fitted (C)	Actual (D)	Ratio (D/C)
Average	2.44%	3.90%	1.78	1.43%	2.95%	2.31
<u>World War II</u>						
Austria	1.37%	3.80%	2.77	0.85%	3.80%	4.47
Belgium	1.68%	3.30%	1.97	0.85%	2.84%	3.35
Denmark	2.72%	2.88%	1.06	1.59%	2.56%	1.61
France	1.25%	3.92%	3.14	1.20%	3.14%	2.61
Germany						
Italy	1.99%	4.36%	2.19	1.40%	3.76%	2.69
Japan	3.18%	6.65%	2.09	1.91%	5.64%	2.95
Netherlands	2.93%	3.25%	1.11	1.53%	2.37%	1.54
Norway				1.72%	3.41%	1.98
Switzerland						
<u>World War I</u>						
Finland	2.73%	3.70%	1.35	1.76%	3.06%	1.74
Sweden	2.16%	3.34%	1.55	1.50%	2.66%	1.77
UK				1.08%	1.73%	1.60
<u>Depression</u>						
Australia	2.81%	4.12%	1.47	0.53%	2.07%	3.94
Canada	4.03%	3.60%	0.89	2.39%	2.34%	0.98
US				1.69%	1.90%	1.12

Table 5

Relationship Between Post-Transition Growth Rates and Level Changes

(only countries with transition periods)

$$DROG_i = \pi_1 + \pi_2\hat{\theta}_i + \epsilon_i$$

	Constant	$\hat{\theta}$	NOBs	R^2
Aggregate	1.2826 (4.74)	-0.7833 (-2.44)	11	0.399
Per Capita	1.6110 (4.31)	-1.1566 (-2.44)	14	0.332

t-statistics in parentheses

a tendency to increase over time, then one might expect a linearization of such a process (caused by the presence of Olson-type rigidities). Following a period of major upheaval, these rigidities are removed and the economy can reap the benefits of a more efficient reallocation of resources.

IV. CONCLUSIONS

The findings of this study show that each of the 16 OECD countries analyzed exhibited a significant trend break over the past one and a quarter century. Once the endogenously determined trend breaks are accounted for, the unit root null, which could not be rejected otherwise (with the exception of the United States), can be rejected for the majority of these countries.

Trend stationarity is necessary for convergence to a steady state growth path. The determination of significant trend breaks enables the calculation of asymptotic growth rates for each subperiod. These "steady state" rates are markedly higher following the breaks. This is still true after omitting the period of transition back to the prebreak steady state path. This evidence that steady state growth rates appear to be growing over extended periods of time is in contradiction with the predictions of the neoclassical growth model as well as with Kaldor's (1961) stylized fact that growth rates remain steady over time. However, increasing growth is compatible with Romer-type endogenous growth models. Furthermore, increases in the growth rates also appear to be significantly related to the decreases in income *levels* that coincided with the breaks. The combination of these two findings allows us to reconcile Romer's and Olson's theories about economic growth.

APPENDIX: AUGMENTED DICKEY-FULLER TESTS

The Augmented Dickey-Fuller test involves regressing the first-difference of a variable on a constant, trend, its lagged level, and k first-differences,

$$\Delta y_t = \mu + \beta t + \alpha y_{t-1} + \sum_{j=1}^{k} c_j \Delta y_{t-j} + \varepsilon_t ,$$

where y is the logarithm of real GDP. The null hypothesis of a unit root is rejected if α, the coefficient on the lagged level of output, is significantly different from zero. While the asymptotic distribution of the t-statistic for α is non-normal, critical values have been calculated by, among many others, MacKinnon (1991). The absolute value of the t-statistic for α is often called the Dickey-Fuller t-statistic.

We follow the procedure suggested by Campbell and Perron (1991) to select the value of k. Start with an upper bound on k chosen *a priori*. If the last included lag is significant, choose the upper bound. If not, reduce k by one until the last lag becomes significant. If no lags are significant, set $k = 0$. Following Perron (1989) and Zivot and Andrews (1992), we set the upper bound on k to equal 8 and the criterion for significance of the t-statistic on the last lag equal to 1.60.[23]

The results of the ADF tests are reported in Table A1. For 15 of the 16 countries, the null hypothesis of a unit root cannot be rejected at the 10 percent level for either aggregate or per capita real GDP. The exception is the United States, where the null can be rejected at the 5, but not the 1, percent level for both variables. Since Nelson and Plosser (1982), using annual

[23] While alternatives to our selection criteria exist, we follow the identical procedure used by Perron and Zivot and Andrews to ensure that, if our results differ from theirs, the differences cannot be caused by the choice of lag length selection criteria.

Table A1 **Dickey-Fuller t-Statistics**

Real GDP (through 1989)

$$\Delta y_t = \mu + \beta t + \alpha y_{t-1} + \sum_{j=1}^{k} c_j \Delta y_{t-j} + \varepsilon_t$$

Country	Aggregate			Per Capita		
	First Year of Sample	Dickey-Fuller t-statistic ($t_{\hat{\alpha}}$)	k	First Year of Sample	Dickey-Fuller t-statistic ($t_{\hat{\alpha}}$)	k
Australia	1860	2.09	2	1870	1.37	2
Austria	1870	1.71	0	1870	1.58	0
Belgium	1860	1.13	5	1870	0.71	5
Canada	1870	1.84	8	1870	1.62	8
Denmark	1860	2.30	2	1870	1.58	2
Finland	1860	1.52	4	1870	1.48	4
France	1860	1.24	5	1870	1.64	5
Germany	1860	2.43	2	1870	1.85	2
Italy	1861	1.75	1	1870	1.66	1
Japan	1885	1.27	0	1885	1.10	0
Netherlands	1900	2.58	1	1900	2.47	1
Norway	1865	0.98	8	1870	0.85	8
Sweden	1860	1.37	5	1870	1.72	5
Switzerland	1899	2.09	1	1899	2.57	1
U.K.	1860	1.10	8	1870	0.46	8
U.S.A.	1869	3.61 *	6	1870	3.63 *	6

* Significant at the 5% level.

data for 1909-1970, cannot reject the unit root null for either aggregate or per capita real GNP for the United States at the 10 percent level, this accords with the conjecture, expressed by Christiano and Eichenbaum (1990), that the failure to reject unit roots in real GNP may be related to the short time span of available data.[24] Our results for the other 15 countries, however, using equally long spans of data, do not support this conjecture. If the unit root null cannot be rejected with 130 years of annual data, it does not appear likely that searching for additional data will make much difference.

[24] The power of unit root tests, as discussed by Campbell and Perron (1991), depends on the span of the data rather than on the number of observations.

Table A2 Sequential Unit Root Tests for *Aggregate* Real GDP

Panel A

$$\Delta y_t = \mu + \theta DU_t + \beta t + \gamma DT_t + \alpha y_{t-1} + \sum_{j=1}^{k} c_j \Delta y_{t-j} + \varepsilon_t$$

Country	First Year	Year of Break	k	$\hat{\mu}$	$\hat{\theta}$	$\hat{\beta}$	$\hat{\gamma}$	$\hat{\alpha}$	Model
Australia	1860	1925	8	1.53 (4.27)	-0.19 (-4.02)	0.0050 (3.73)	0.0020 (3.47)	-0.18 (-4.15)	C
Austria	1870	1944	2	2.73 (4.89)	-1.02 (-4.35)	0.0042 (4.07)	0.0106 (4.45)	-0.31 (-4.86)	C
Belgium	1860	1939	3	2.48 (5.81)	-0.51 (-5.60)	0.0045 (5.49)	0.0052 (5.66)	-0.27 (-5.77)	C
Canada	1870	1928	7	2.91 (6.02)	-0.27 (-4.85)	0.0148 (5.96)	0.0023 (3.57)	-0.37 (-5.97)	C
Denmark	1860	1939	3	1.95 (4.25)	-0.20 (-3.23)	0.0069 (4.27)	0.0020 (3.09)	-0.25 (-4.21)	C
Finland	1860	1913	3	2.09 (6.04)	-0.27 (-5.54)	0.0080 (6.00)	0.0035 (4.80)	-0.29 (-6.01)	C
France	1860	1939	8	4.64 (6.60)	-1.29 (-6.46)	0.0053 (6.26)	0.0140 (6.48)	-0.42 (-6.60)	C
Germany*	1860	1952	1	10.15 (364.1)		0.0221 (44.6)	0.0051 (13.6)	-0.30 (-5.40)	B
Italy	1861	1940	1	1.79 (4.18)	-0.44 (-3.64)	0.0035 (4.14)	0.0049 (3.73)	-0.18 (-4.16)	C
Japan	1885	1944	8	4.84 (6.34)	-2.01 (-6.15)	0.0166 (6.09)	0.0204 (6.14)	-0.52 (-6.31)	C
Netherlands	1900	1939	7	3.40 (4.24)	-0.61 (-3.25)	0.0118 (3.69)	0.0057 (2.71)	-0.41 (-4.23)	C
Norway	1865	1944	0	1.17 (3.61)	-0.15 (-1.88)	0.0036 (3.48)	0.0024 (2.51)	-0.16 (-3.55)	C
Sweden	1860	1913	5	1.42 (4.29)	-0.17 (-3.99)	0.0036 (4.07)	0.0023 (3.71)	-0.17 (-4.24)	C
Switzerland	1899	1944	0	0.99 (4.17)	0.09 (5.28)	0.0021 (2.49)		-0.12 (-3.84)	A
U.K.	1860	1918	5	3.42 (6.64)	-0.16 (-6.25)	0.0060 (6.44)	0.0011 (3.84)	-0.31 (-6.61)	C
U.S.	1869	1929	7	4.71 (5.76)	-0.09 (-3.87)	0.0147 (5.69)		-0.42 (-5.71)	A

t-statistics in parentheses. All data end in 1989.
* The model B estimation for Germany uses the two-step procedure.

Table A2 (cont) Sequential Unit Root Tests for *Per Capita* Real GDP

Panel B

$$\Delta y_t = \mu + \theta DU_t + \beta t + \gamma DT_t + \alpha y_{t-1} + \sum_{j=1}^{k} c_j \Delta y_{t-j} + \varepsilon_t$$

Country	First Year	Year of Break	k	$\hat{\mu}$	$\hat{\theta}$	$\hat{\beta}$	$\hat{\gamma}$	$\hat{\alpha}$	Model
Australia	1870	1927	8	2.54 (4.60)	-0.33 (-4.30)	0.0016 (3.12)	0.0049 (4.20)	-0.31 (-4.61)	C
Austria	1870	1944	5	3.76 (6.00)	-1.53 (-5.68)	0.0040 (4.70)	0.0183 (5.77)	-0.51 (-5.99)	C
Belgium	1870	1939	3	2.64 (6.28)	-0.65 (-6.18)	0.0029 (5.59)	0.0079 (6.23)	-0.34 (-6.26)	C
Canada	1870	1928	7	3.22 (6.45)	-0.30 (-5.63)	0.0100 (6.18)	0.0026 (4.17)	-0.46 (-6.41)	C
Denmark	1870	1939	4	3.06 (5.86)	-0.45 (-5.50)	0.0066 (5.84)	0.0053 (5.44)	-0.42 (-5.84)	C
Finland	1870	1913	4	1.53 (4.81)	-0.23 (-4.43)	0.0040 (4.56)	0.0035 (3.62)	-0.23 (-4.82)	C
France	1870	1939	8	3.30 (6.07)	-0.96 (-5.89	0.0053 (5.62)	0.0115 (5.87)	-0.45 (-6.06)	C
Germany*	1870	1946	0	6.59 (210.4)		0.0167 (26.6)	0.0079 (17.1)	-0.30 (-4.57)	B
Italy	1870	1939	1	1.35 (4.37)	-0.44 (-3.96)	0.0027 (3.98)	0.0054 (4.00)	-0.19 (-4.36)	C
Japan	1885	1944	8	3.29 (6.60)	-1.91 (-6.46)	0.0102 (5.97)	0.0215 (6.47)	-0.53 (-6.57)	C
Netherlands	1900	1939	7	3.53 (4.74)	-0.73 (-4.03)	0.0071 (3.41)	0.0078 (3.50)	-0.48 (-4.74)	C
Norway	1870	1939	3	1.31 (3.62)	-0.27 (-3.56)	0.0033 (4.06)	0.0035 (3.45)	-0.19 (-3.62)	C
Sweden	1870	1916	4	2.24 (5.55)	-0.28 (-5.02)	0.0047 (5.30)	0.0044 (4.86)	-0.31 (-5.55)	C
Switzerland	1899	1944	0	1.29 (4.54)	0.08 (4.94)	0.0026 (3.18)		-0.17 (-4.37)	A
U.K.	1870	1918	8	2.12 (5.45)	-0.19 (-5.69)	0.0029 (4.67)	0.0023 (4.45)	-0.27 (-5.42)	C
U.S.	1870	1929	8	4.18 (5.98)	-0.21 (-4.31)	0.0090 (5.63)	0.0023 (3.46)	-0.54 (-5.95)	C

t-statistics in parentheses. All data end in 1989.

* The model B estimation for Germany uses the two-step procedure.

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