MONASH University
Business and Economics

Department of Economics

issn 1441-5429

Discussion paper 10/08

# IS THE OUTPUT-CAPITAL RATIO CONSTANT IN THE VERY LONG RUN?

Jakob B. Madsen[*] Russell Smyth[**]

**Abstract:**

A key prediction of standard models of economic growth is that the output-capital ratio is constant along the economy's balanced growth path. Using data for 16 OECD countries over 135 years we examine whether the output-capital ratio reverts to a constant in the long run using univariate and panel stationarity tests with structural breaks. Univariate unit root tests with one and two breaks in the mean suggest that, in most circumstances, the output-capital ratio fails to revert towards a mean. However, when we allow for up to five breaks in the mean we find that for 15 of the 16 countries, the output-capital ratio is stationary and that the output-capital ratio is also panel stationary.

[*] Department of Economics, Monash University; Economic Policy Research Unit and Finance Research Unit, Department of Economics, University of Copenhagen.

[**] Department of Economics, Monash University

## 1 Introduction

In an influential paper Kaldor (1961) stated that models of economic growth should be able to explain a constant output-capital (*Y-K*) ratio in the long run. Despite constancy of the *Y-K* ratio being one of the key predictions of models of economic growth, surprisingly little work have been undertaken to examine whether the *Y-K* ratio is in fact constant in the long run. Furthermore, the available evidence in the literature is based on approximately the same data set. Based on Maddison's (1982) data for seven OECD countries Romer (1989) finds that there is a close relationship between the growth in capital and income per hour worked using graphical evidence. Maddison (1982, Ch. 3) contains a similar discussion. Klein and Kosobud (1961) find that the *Y-K* ratio displays a significant downward trend for the United States over the period from 1900 to 1953. The only statistical treatment of the issue is by D'Adda and Scorcu (2003). These authors examine whether there is a long-run relationship between output and capital using the Gregory and Hansen (1996) test for cointegration and test whether the restriction on capital is equal to one, employing data spanning between 41 and 122 years for seven OECD countries. D'Adda and Scorcu (2003) find, at best, mixed support for the prediction that the *Y-K* ratio is mean reverting.

Using data for 16 OECD countries over 135 years this paper first tests whether the *Y-K* ratio is mean reverting employing univariate unit root tests with one and two changes in the mean proposed by Perron and Vogelsang (1992) and Clemente *et al.* (1998). Following this exercise we proceed to employ a panel unit stationarity test, which allows for multiple changes in the mean proposed by Carrion-i-Silvestre *et al* (2005). The Carrion-i-Silvestre *et al* (2005) test has the advantage that it allows for heterogeneity in the panel data setting. Thus, in addition to the panel result, one can obtain results for individual countries with up to five breaks. The study differs from D'Adda and Scorcu (2003) in that we use data for a larger number of countries over a longer time period and we examine whether the *Y-K* ratio is stationary using univariate and panel unit root tests with structural breaks. D'Adda and Scorcu (2003) do not employ unit root tests to examine whether the *Y-K* ratio is stationary.

The paper is set out as follows. The next section demonstrates that key economic growth models predict the *Y-K* ratio will be constant in the long run. Section 3 discusses the data used in the study and examines movements in the *Y-K* ratio over time. The results of the univariate and panel unit root tests applied to the *Y-K* ratio are presented in Section 4 and the implications of the findings are in the conclusion.

## 2. *Y-K* Constancy on the Balanced Growth Path

Most well-known models of economic growth predict that the *Y-K* ratio will be constant in the long run. These models include those proposed by Harrod (1959), Domer (1947), Kaldor (1961), Solow (1956), Lucas (1988) and Romer (1986). To preserve space, only the predictions of the Solow, Ramsey and Lucas models are shown here.

Consider the capital accumulation equation:

$$\dot{K} = I - \delta K,$$

where $I$ is gross investment, $K$ is capital stock, and $\delta$ is the depreciation rate. Solow (1956) assumes that a constant fraction of income is saved and subsequently invested so that $I = sY$, where $s$ is the savings propensity and $Y$ is income. The capital accumulation equation can be written as:

$$\frac{\dot{K}}{K} = s\frac{Y}{K} - \delta.$$

Defining $k = K/AL$ and $y = Y/AL$, where $A$ is labor efficiency, the capital accumulation equation can be written as

$$\dot{k} = sy - k(n + g + \delta), \qquad (1)$$

where $n$ is the population growth rate, $g$ is the growth in labor efficiency, and $\delta$ is the depreciation rate. Along the balanced growth path, on which $\dot{k} = 0$, the *Y-K* ratio is given by:

$$\frac{Y}{K} = \frac{n + g + \delta}{s}, \qquad (2)$$

which is constant for given $n$, $g$, $\delta$, and $s$. Since the investment ratio has been approximately 10% and $n + g + \delta$ is predominantly in the interval between 5% and 10% for the OECD countries over the past century the Solow model predicts an output-capital ratio in the range between one half and one.

The key equations of the Ramsey model consist of the simultaneous first-order differential system (see for example Barro and Sala-I-Martin, 2004):

$$\dot{k} = f(k) - c - k(n+g)$$

and

$$\frac{\dot{c}}{c} = \frac{f'(k) - \rho - \theta g}{\theta},$$

where $c$ is per capita consumption in efficiency units, $n$ is population growth, $\rho$ is the rate of time preference and $\theta$ is the coefficient of relative risk aversion. The Euler equation is based on a constant-relative-risk-aversion utility function. Assuming Cobb-Douglas technology, the steady state *Y-K* ratio is given by:

$$\frac{Y}{K} = \frac{\rho + \theta g}{\alpha},$$

where $\alpha$ is the output elasticity of capital. Assuming perfect competition, $\alpha$ is capital's share of income. Setting $\rho$ = 0.02, $\alpha$ = 0.3, $\theta$ = 2 and $g$ = 0.02, yields a *Y-K* ratio of 2 on the balanced growth path, which is well above the predictions of the Solow model.

To show that the Lucas (1988) model also predicts a constant *Y-K* ratio consider the following two key equations in his model:

$$Y_t = K_t^{\alpha}\left[(1-a_H)H\right]_t^{\beta}, \qquad 0<\alpha<1,\ 0<\beta<1,\ 1<\alpha+\beta \tag{3}$$

and

$$\dot{K}_t = sY_t, \tag{4}$$

where $H$ is the contribution of workers to production and, as such, includes the influence of human capital and physical labor on production, and $a_H$ is the fraction of human capital used in production. These equations are simplified versions of the Lucas model in which $a_H$ and $s$ are endogenous. Substituting (3) into (4) and differentiating yields after some manipulations:

$$\dot{g}_{K,t} = (\alpha - 1)g_{K,t}^2 + \beta g_{H,t} g_{K,t},$$

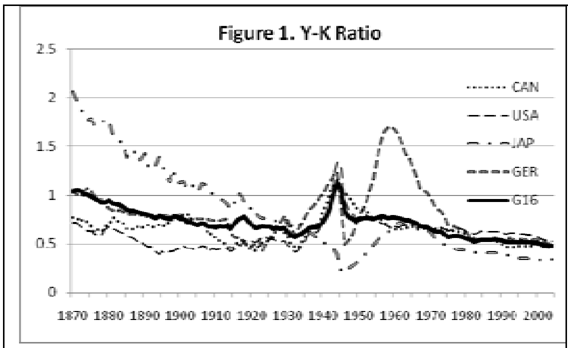
where $g_K$ and $g_H$ are the growth rates in *K* and *H*. Along the balanced growth path the growth rate in capital stock is given by:

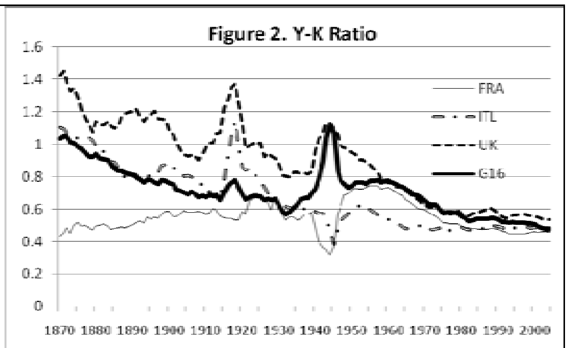
$$g^*_{K,t} = \frac{\beta}{(\alpha - 1)} g_{H,t} \qquad (5)$$

Log differentiating (3) and substituting into (5) shows that output and capital grow at the same rate along the balanced growth path and, therefore, that the *Y-K* ratio is constant in the steady-state.

### 3. Data

The following 16 OECD countries are included in the data set over the period 1870 to 2004: Canada, the United States, Japan, Australia, Belgium, Denmark, Finland, France, Germany, Italy, the Netherlands, Norway, Spain, Sweden, Switzerland, and the United Kingdom. These countries are henceforth referred to as the G16. Capital stock is calculated by applying the inventory perpetual method to investment in machinery and to equipment and investment in non-residential buildings and structures, separately. The capital stock is estimated separately for machinery and equipment and structures because the share of machinery and equipment in total investment has increased markedly in the OECD over the course of the past two centuries. Coupled with the fact that depreciation rates are substantially higher for machinery and equipment than structures, the precision gain from disaggregation is large. Income is measured as economy-wide GDP. The data construction is set out in detail in the Data Appendix.




**Note**. G16 is a weighted average of the G16 countries where GDP at PPP have been used as weights.

Figures 1 and 2 show the *Y-K* ratio for each of the G7 countries and a weighted average of the G16 countries. For the G16 countries the ratio has fluctuated around a declining trend that has stabilized around 0.5 since 1980. The marked increase in the *Y-K* ratio during World War II is driven by the events in the United States, Canada and Germany. For the United States and Canada capital stock did not adjust fully to the positive demand shock while the destruction of capital stock in Germany during the war drove the *Y-K* ratio. The marked upswing in the German *Y-K* ratio from 1945 to 1960 occurred because the capital stock was slow to adjust to the marked increase in economic activity. The decreasing *Y-K* ratio for Japan over the period from 1870 to around 1980 predominantly reflects an increasing savings ratio over the same period. Finally, among the G16 countries there has been a convergence in the *Y-K* ratio over time. The standard deviation of the log of *Y-K* decreased from 0.52 in 1870 to 0.12 in 2004.

The path in the *Y-K* ratio on medium term frequencies is remarkable. The ratio declines in periods of high economic growth. These are the periods from 1870 to 1913 and from 1950 to 1974. An important question is why the marginal productivity of capital, and hence the returns to capital, is declining in periods of high economic growth? According to the Solow growth model returns to capital are positively related to economic growth along the balanced growth path on which all growth is driven by technological progress. However, periods in the reduction of the *Y-K* ratio have predominantly been driven by an increasing savings ratio and, therefore, decreasing time preferences that would drive down the required returns to capital. Furthermore, the Schumpeterian theories of Aghion and Howitt (1998, Ch. 3) suggest that periods of strong economic growth are associated with a large degree of creative destruction that automatically lowers the value of existing capital and, therefore, lowers the average returns to capital.

The decline in the *Y-K* ratio for the G16 countries is likely to have been underestimated because the capital stock is measured by an error – particularly machinery and equipment capital stock. The inherent problem with most investment data is that quality adjustment has not been properly dealt with and, consequently, the growth in real investment is underestimated (see Gordon, 1990). Using Hedonic pricing for the United States over the period 1948 to 1981, Gordon (1990) finds that the ratio of official estimates of the investment deflator and the quality adjusted investment deflator has increased in the post World War II period in the United States.

In other words the official estimates of investment underestimates the growth in real investment because the investment deflator exaggerates the increase in prices of investment goods. If Gordon's finding applies to countries other than the United States and back in history the growth in capital stock over the past 135 years has been underestimated. This in turn means that the *Y-K* ratio in Figures 1 and 2 have declined more than shown in the graphs and, therefore, the data are biased in favour of mean reversion of the *Y-K* ratio.

Overall the figures suggest that there have been a tendency for the *Y-K* ratio to decrease slightly over time. The question is whether the decrease has been sufficiently strong to overrule the predictions of economic growth models that the *Y-K* ratio is constant.

## 4. Is the *Y-K* Ratio Stationary?

*Univariate Unit Root Tests*

To examine whether the *Y-K* ratio is mean reverting we commenced through applying the Augmented Dickey Fuller (ADF) and Phillips and Perron unit root tests without a trend as well as the KPSS stationarity test without a trend. The results are not reported to conserve space. The ADF test rejected the unit root null for five countries (31 per cent of the sample); namely, Italy, Netherlands, United Kingdom, United States and Switzerland. The KPSS stationarity test failed to reject the null of stationarity for the same five countries. The Phillips-Perron test could only reject the unit root null for two countries (13 per cent of the sample) – Sweden and Switzerland. Taken together, these results suggest that for most of the countries the *Y-K* ratio can be regarded as non-stationary. However, a limitation of conventional unit root and stationarity tests such as these is that they do not take into account potential structural breaks in the *Y-K* ratio. Perron (1989) pointed out that power to reject the unit root null declines if the data contains a structural break that is ignored. Potential structural breaks in the *Y-K* ratio over the period 1870-2004 include the 1890s Depression, the Great Depression and the World Wars to name just a few.

In the presence of one structural break a better alternative is the use of the Perron and Vogelsang (1992) tests. When the innovational outlier case is considered, the Perron and Vogelsang (1992) statistics can be obtained from the estimation of this model:

$$YK_t = \mu + \delta DTB_t + dDU_t + \rho YK_{t-1} + \sum_{t=1}^{k} c_t \Delta YK_{t-1} + \varepsilon_t \,, \qquad (6)$$

and from the subsequent use of the pseudo $t$-ratio for testing whether the autoregressive parameter is 1. The date of the break can be estimated either by minimizing the statistics or by optimizing the $t$-ratio for testing the significance of the parameter $d$, which measures the magnitude of the break under the alternative hypothesis. In Equation (6), $DTB_t$ is a pulse variable that takes the value 1 if $t = TB + 1$ and 0 otherwise, $DU_t$ takes the value 1 whenever $t > TB$ and 0 otherwise, with $TB$ being the period where the mean of the variable changes.

In some cases, the presence of a single break in the mean is not enough to capture the behaviour of the variable. Clemente *et al.* (1998) proposed a similar testing procedure to that in Perron and Vogelsang (1992) but considering the case of two changes in the mean:

$$YK_t = \mu + \delta_1 DTB_{1t} + \delta_2 DTB_{2t} + d_1 DU_{1t} + d_2 DU_{2t} + \rho YK_{t-1} + \sum_{t=1}^{k} c_t \Delta YK_{t-1} + \varepsilon_t \qquad (7)$$

Clemente *et al.* (1998) obtain the minimum value of the pseudo $t$-ratio for testing whether the autoregressive parameter is 1 for the full range of possible times of the break. In Equation (7) $DTB_{1t}$ is a pulse variable that takes the value 1 if $t = TB_1 + 1$ and zero otherwise. $DU_{1t}$ takes the value 1 whenever $t > TB_1$ and zero otherwise, with $TB_1$ being the period where the mean of the variable changes ($i$ = 1,2). Both of these tests can be used to analyse the integration order of a variable in the presence of some changes in the mean. In addition, these tests also provide information about the location when the structural break is more feasible to happen.

The results for the Perron and Vogelsang (1992) test are reported in Table 1 and the results for the test proposed by Clemente *et al.* (1998) are reported in Table 2. The Perron and Vogelsang (1992) test rejects the unit root null for three countries

**Table 1. Results of Perron and Vogelsang (1992) unit root test with one structural break for YK ratio of Individual countries (Innovative Outlier Case)**

| **Country** | **$TB_1$** | ***K*** | **$DU_1$** | **(ρ-1)** |
|---|---|---|---|---|
| Australia | 1896 | 3 | 0.012*<br>(1.804) | -0.035<br>(-2.149) |
| Belgium | 1942 | 0 | 0.020***<br>(4.926) | -0.194**<br>(-4.937) |
| Canada | 1972 | 2 | -0.014*<br>(-1.883) | -0.072<br>(-3.263) |
| Denmark | 1938 | 0 | -0.015**<br>(-2.468) | -0.074<br>(-2.483) |
| Finland | 1953 | 4 | -0.022***<br>(-3.205) | -0.144<br>(-3.563) |
| France | 1969 | 1 | -0.011*<br>(-1.827) | -0.091<br>(-3.090) |
| Germany | 1922 | 10 | 0.008<br>(0.764) | -0.037<br>(-1.695) |
| Italy | 1917 | 2 | -0.039***<br>(-4.769) | -0.110**<br>(-5.326) |
| Japan | 1879 | 3 | -0.045*<br>(-1.965) | -0.036<br>(-3.111) |
| Netherlands | 1912 | 1 | -0.029***<br>(-4.469) | -0.151**<br>(-4.778) |
| Norway | 1992 | 8 | 0.012**<br>(2.513) | -0.076<br>(-3.286) |
| Spain | 1882 | 6 | -0.074**<br>(-2.586) | -0.040<br>(-4.088) |
| Sweden | 1950 | 10 | -0.031**<br>(-2.227) | -0.080<br>(-2.284) |
| Switzerland | 1933 | 10 | 0.008*<br>(1.914) | -0.075<br>(-3.293) |
| UK | 1942 | 5 | -0.027***<br>(-2.958) | -0.065<br>(-3.286) |
| USA | 1946 | 3 | 0.009<br>(1.150) | -0.101<br>(-3.821) |

Notes: The Critical value of one break IO model at five percent is -4.270. Figures in parenthesis are t-statistics. $^{*}$ ($^{**}$) $^{***}$ denote statistical significance at the 10%, 5% and 1% levels respectively.

**Table 2. Results of Clemente, Montanes and Reyes (1998) unit root test with two structural breaks for YK ratio of Individual countries (Innovative Outlier Case)**

| Country | $TB_1$ | $TB_2$ | *k* | $DU_1$ | $DU_2$ | (ρ-1) |
|---|---|---|---|---|---|---|
| Australia | 1939 | 1943 | 3 | 0.110***<br>(6.731) | -0.119***<br>(-7.072) | -0.054<br>(-3.864) |
| Belgium | 1917 | 1942 | 0 | -0.001***<br>(-0.526) | 0.023***<br>(5.012) | -0.235**<br>(-6.185) |
| Canada | 1938 | 1943 | 1 | 0.096***<br>(5.483) | -0.103***<br>(-5.784) | -0.081<br>(-4.231) |
| Denmark | 1895 | 1961 | 0 | -0.027***<br>(-3.964) | -0.032***<br>(-3.971) | -0.200<br>(-4.524) |
| Finland | 1916 | 1953 | 4 | 0.000***<br>(-0.043) | -0.026***<br>(-3.984) | -0.164<br>(-4.156) |
| France | 1943 | 1965 | 1 | 0.036***<br>(4.689) | -0.045***<br>(-5.085) | -0.175**<br>(-5.527) |
| Germany | 1945 | 1968 | 10 | 0.091***<br>(5.913) | -0.118***<br>(-6.516) | -0.132<br>(-5.405) |
| Italy | 1915 | 1917 | 2 | 0.133***<br>(4.664) | -0.169***<br>(-5.756) | -0.118**<br>(-6.532) |
| Japan | 1879 | 1916 | 3 | -0.064***<br>(-2.716) | -0.047***<br>(-2.627) | -0.085<br>(-3.943) |
| Netherlands | 1915 | 1943 | 6 | -0.044***<br>(-6.270) | 0.002***<br>(0.376) | -0.211<br>(-5.232) |
| Norway | 1912 | 1992 | 0 | -0.008***<br>(-1.946) | 0.013***<br>(2.721) | -0.102<br>(-4.277) |
| Spain | 1882 | 1924 | 6 | -0.115***<br>(-3.887) | -0.071***<br>(-3.547) | -0.101<br>(-5.166) |
| Sweden | 1929 | 1955 | 10 | -0.050***<br>(-3.939) | -0.052***<br>(-3.095) | -0.228<br>(-3.915) |
| Switzerland | 1943 | 1970 | 10 | 0.039***<br>(4.626) | -0.029***<br>(-4.238) | -0.183**<br>(-5.377) |
| UK | 1916 | 1954 | 5 | -0.026***<br>(-3.185) | -0.041***<br>(-3.501) | -0.132<br>(-4.764) |
| USA | 1940 | 1944 | 2 | 0.237<br>(9.118) | -0.219<br>(-8.966) | -0.189**<br>(-6.908) |

Notes: The Critical value of two break IO model at five percent is –5.490. Figures in parenthesis are t-statistics. * (**) *** denote statistical significance at the 10%, 5% and 1% levels respectively.

(Belgium, Italy and the Netherlands). The Clemente *et al.* (1998) test rejects the unit root null for five countries (Belgium, France, Italy, Switzerland and the United States). Comparing the no-break, one break and two break cases, as a rule of thumb, the one beak case should be preferred to the no-break case if the break is statistically significant and the two break case should be preferred if the second break is statistically significant. The one and two break cases give the same results for all countries except for France, Netherlands, Switzerland and the United States. For France, Netherlands and Switzerland the second break is significant, but for the United States neither break is significant. Thus, on the basis of a no-break, one and two break hybrid list we conclude that the unit root null is rejected for only five countries (Belgium, France, Italy, Switzerland and the United States), just under one-third of the sample. Overall the findings from these unit root tests provide little support for the proposition that the *Y-K* ratio is stationary.

The structural break is statistically significant in the one break case for all countries except Germany and the United States. The structural break in Australia occurs during the 1890s Depression. The structural break in Italy and the Netherlands occurs at the time of World War I. The structural break in Germany occurs during the 1922-1923 bout of hyperinflation in that country. The structural break in Switzerland occurs during the Great Depression. The structural break in Belgium, Denmark, Finland, Sweden, the United Kingdom and the United States occurs in World War II or in the period of recovery following the war. The structural break in France closely follows the liberalization of French financial markets over the period 1965-1967. The break for Canada corresponds with the collapse of the Bretton Woods agreement at the beginning of the 1970s and occurs just prior to the first oil price shock. The structural break in Norway coincides with the European recession of the early 1990s. In the two break case both breaks are statistically significant for all countries except the United States. For just over half of the countries one of the two breaks in the two break case are within five years of the break in the one break case (Belgium, Finland, Italy, Japan, Netherlands, Norway, Spain, Sweden and the United States). In the two break case most of the breaks are associated with major episodes such as the 1890s depression, the Great Depression and the World Wars or in the recovery phase following World War II.

*Panel Stationarity Test*

The Carrion-i-Silvestre *et al* (2005) test is designed for the null hypothesis of stationarity after taking structural breaks into account. This test is not restricted to only two structural breaks but allows for multiple breaks. It is a panel stationarity root test that allows for structural shifts in either the mean and/or the trend of the individual time series. This test, therefore, allows for heterogeneity, which permits each individual in the panel to have a different number of breaks at different dates. In what follows, we discuss the model that includes structural shifts in the mean.

In a panel setting the *Y-K* ratio will be defined as $YK_{it}$ with $i = 1,.....,N$ being individual *Y-K* ratios and $t = 1,.....,T$ . The null hypothesis of stationarity with levels shift is tested based on:

$$YK_{i,t} = \alpha_i + \sum_{k=1}^{m} \theta_{i,k} DU_{i,k,t} + \varepsilon_{i,t} \ , \qquad (8)$$

where, $DU_{i,k,t}$ is a dummy variable defined as $DU_{i,k,t} = 1$ for $t > T_{b,k}^{i}$ and 0, otherwise; $\varepsilon_{i,t}$ is assumed to be a stationary process; and $T_{b,k}^{i}$ denotes the *k*th date of the break for the *i*th country, $\mathrm{k} = (1,...,\mathrm{m_i}), \mathrm{m_i} \geq 1$. As noted above, the model includes individual shifts in the mean caused by structural breaks. $\theta_{i,k}$ measures the effect of structural breaks on individual series.

The results testing the null of stationarity allowing for up to five structural breaks in the *Y-K* ratio for each of the 16 countries are reported in Table 3. The table reports the test statistics, the finite sample critical values based on Monte Carlo simulations with 20,000 replications and the break dates. For 15 of the 16 countries we are unable to reject the null of stationarity, meaning that once we allow for up to five structural breaks, the *Y-K* ratio is mean reverting for 15 of the 16 countries. The one country for which the unit root null is rejected is Switzerland at the 2.5% level. A proviso to this conclusion is that as Hansen (2001) notes the addition of breaks makes the difference between non-stationary and regime-wise stationary less clear and that with enough breaks the segmented means will accurately approximate a non-stationary trend. Having said this, in Table 3 Denmark is the only country where all five breaks were

**Table 3: Results of Carrion-i-Silvestre *et al.* (2005) stationarity test of YK ratio with levels shifts for individual countries**

| Country | t-statistic (Quadratic ) | $TB_1$ | $TB_2$ | $TB_3$ | $TB_4$ | $TB_5$ | Finite Sample Critical values | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | 90 | 95 | 97.5 | 99 |
| Australia | 0.019 | 1892 | 1912 | 1941 | 1961 | | 0.027 | 0.031 | 0.035 | 0.039 |
| Belgium | 0.012 | 1899 | 1919 | 1944 | 1974 | | 0.03 | 0.036 | 0.042 | 0.05 |
| Canada | 0.017 | 1909 | 1940 | 1961 | | | 0.045 | 0.056 | 0.067 | 0.08 |
| Denmark | 0.013 | 1897 | 1919 | 1939 | 1959 | 1981 | 0.023 | 0.027 | 0.031 | 0.036 |
| Finland | 0.030 | 1894 | 1920 | 1952 | 1977 | | 0.026 | 0.03 | 0.034 | 0.04 |
| France | 0.023 | 1922 | 1945 | 1965 | | | 0.067 | 0.086 | 0.105 | 0.129 |
| Germany | 0.012 | 1918 | 1944 | 1964 | 1984 | | 0.056 | 0.073 | 0.089 | 0.112 |
| Italy | 0.024 | 1895 | 1915 | 1935 | | | 0.044 | 0.052 | 0.061 | 0.071 |
| Japan | 0.030 | 1889 | 1944 | 1964 | | | 0.034 | 0.039 | 0.045 | 0.051 |
| Netherlands | 0.018 | 1901 | 1946 | | | | 0.046 | 0.053 | 0.06 | 0.07 |
| Norway | 0.012 | 1889 | 1916 | 1939 | 1981 | | 0.025 | 0.029 | 0.032 | 0.036 |
| Spain | 0.025 | 1889 | 1929 | | | | 0.049 | 0.057 | 0.066 | 0.08 |
| Sweden | 0.015 | 1889 | 1930 | 1976 | | | 0.031 | 0.035 | 0.039 | 0.044 |
| Switzerland | 0.040*** | 1889 | 1931 | 1957 | | | 0.032 | 0.036 | 0.04 | 0.046 |
| UK | 0.020 | 1914 | 1939 | 1971 | | | 0.052 | 0.064 | 0.078 | 0.096 |
| USA | 0.014 | 1892 | 1941 | 1961 | | | 0.034 | 0.038 | 0.043 | 0.049 |

Notes: The finite sample critical values were computed by means of Monte Carlo simulation using 20,000 replications. *, **, *** and **** denote significance at the 10%, 5%, 2.5% and 1% levels, respectively.

statistically significant; for five countries four breaks were statistically significant; for eight countries three breaks were statistically significant and for two countries only two breaks were statistically significant. Thus, in relatively few cases do we actually require four or five breaks to find evidence of mean reversion. For most countries at least two of the first three breaks are associated with the 1890s Depression, the World Wars and/or the Great Depression. The latter breaks are associated with world events such as the collapse of Bretton Woods (UK), the first oil price shock (Belgium), the second oil price shock and recession of the early 1980s (Finland, Denmark, Germany and Norway) or country specific events such as the credit squeeze (Australia, 1961) or liberalization of French financial markets (France, 1965).

**Table 4: Carrion-i-Silvestre *et al.* (2005) panel test for stationarity of YK ratio**

| | Panel of 16 countries | p-value |
|---|---|---|
| No Breaks (Homogenous) | 6.730** | 0.048 |
| No Breaks (Heterogeneous) | 6.210** | 0.045 |
| Breaks (Homogenous) | 0.215 | 0.415 |
| Breaks (Heterogeneous) | 1.232 | 0.109 |

Notes: ** denotes statistical significance at the 5% level; p-values are based on critical values from Carrion-i-Silvestre *et al.* (2005).

The results of the Carrion-i-Silvestre *et al* (2005) test, without structural breaks and with a maximum of five breaks, are reported in Table 3. We report results for the alternative assumptions that the long-run variance is homogenous or heterogenous. Without structural breaks we reject the null hypothesis of stationarity. However, when we allow for five structural breaks we cannot reject the null hypothesis, implying that with structural breaks the *Y-K* ratio is panel stationary.

**5. Concluding remarks**

Using a data set that spans a longer time period and covers a substantially larger sample of countries than has been previously considered, this paper found mixed evidence for constancy of the *Y-K* ratio in tests allowing for up to two structural breaks in the mean. This finding is consistent with the results obtained in the extant literature, particularly the study by D'Adda and Scorcu (2003). However, the *Y-K* ratio was found to be mean reverting for 15 of 16 OECD countries once we allowed for up to five structural breaks in the mean. Furthermore, the panel unit root test with up to five structural breaks in the mean also provided evidence of the constancy of the *Y-K* ratio for the 16 OECD countries. The main conclusion is that our results support the prediction of economic growth models such as Kaldor (1961) that the *Y-K* ratio is constant in the long run once we accommodate the effects of structural breaks.

Allowing for structural breaks in the econometric tests is important because the balanced growth paths change as economies are subject to shifts to subjective discount factors, population growth rates and other exogenous parameters that vary across economic growth models. Thus, our analysis explicitly acknowledges that the *Y-K* ratio need not be constant in the very long run. However, the *Y-K* ratio is required to be stationary between the structural breaks.

The implications of our findings is that constancy of *Y-K* along a balanced growth path can be imposed on growth models and, therefore, ease the interpretation of factors that determine the balanced growth path. Furthermore, required returns to equity can be assumed to be constant in asset pricing models (see for example Madsen and Davis, 2006). Since expected returns to assets are proportional to the *Y-K* ratio in models with homogeneous technology our results suggest that the imposition of constant expected returns on stocks can be imposed on asset pricing models.

**References**

Abel, A.B. and O.J. Blanchard, 1983, “An Intertemporal Model of Saving and Investment”, *Econometrica*, 51, 675-692.

Aghion, P. and P. Howitt, 1998, *Endogenous Growth*, Cambridge, MA: MIT Press.

Barro, R. J. and X. Sala-i-Martin, 2004, *Economic Growth,* Cambridge, MA: MIT Press.

Carrion-i-Silvestre, J.L., T.D. Barrio-Castro and E. Lopez-Bazo 2005, “Breaking the Panels: An Application to GDP Per Capita”, *Econometrics Journal*, 8, 159-175.

Clemente, J., A. Montanes and M. Reyes 1998, “Testing for a Unit Root in Variables with a Double Change in the Mean”, *Economics Letters*, 59, 175-182.

D’Adda, C. and A.E. Scorcu 2003, “On the Time Stability of the Output-Capital Ratio”, *Economic Modelling*, 20, 1175-1189.

Domar, E.D. 1947, “Expansion and Employment”, *American Economic Review*, 37, 34-35.

Gregory, A.W. and B.E. Hansen 1996, “Residual Based Tests for Cointegration in Models with Regime Shifts”, *Journal of Econometrics*, 70, 99-126.

Gordon, Robert J., 1990, *The Measurement of Durable Goods Prices*. University of Chicago Press for National Bureau of Economic Research.

Hansen, B. 2001, “The New Econometrics of Structural Change: Dating the Breaks in U.S. Labor Productivity”, *Journal of Economic Perspectives*, 15, 117-128.

Harrod, R.F. 1959, “Domar and Dynamic Economics”, *Economic Journal*, 49**,** 451-464.

Im, K-S, H. Pesaran, H. and Y. Shin 2003, “Testing for Unit Roots in Heterogeneous Panels”, *Journal of Econometrics*, 115, 53-74.

Kaldor, N. 1961, Capital Accumulation and Economic Growth in F.A. Lutz and D.C. Hague (Eds) *The Theory of Capital*, New York: Macmillan.

Klein, L.R. and R.F. Kosobud 1961, “Some Econometrics of Growth: Great Ratios of Economics”, *Quarterly Journal of Economics*, 75, 173-198.

Lucas, R.E. 1988, “On the Mechanisms of Economic Development”, *Journal of Monetary Economics*, 22, 3-42.

Maddison, A. 1982, *Phases of Capitalist Development*, Oxford: Oxford University Press.

Madsen, J.B. and E.P. Davis, 2006, “Equity Prices, Productivity Growth and the New Economy,” *Economic Journal*, 116, 791-811.

Perron, P. 1989, “The Great Crash, the Oil Price Shock and the Unit Root Hypothesis”, *Econometrica*, 57, 1361-1401.

Perron, P. and T. Volgesang 1992, “Nonstationarity and Level Shifts with an Application to Purchasing Power Parity”, *Journal of Business and Economic Statistics*, 10, 301-320.

Romer, P.M. 1986, “Increasing Returns and Long-run Growth”, *Journal of Political Economy*, 94, 1002-1037.

Romer, P.M. 1989, “Capital Accumulation in the Theory of Long-run Growth”, in R.J. Barro (ed.) *Modern Business Cycle Theory*, Oxford: Basil Blackwell.

Solow, R.M. 1956, “A Contribution to the Theory of Economic Growth”, *Quarterly Journal of Economics*, 70, 65-94.

**Data Appendix**

**Capital stock of equipment and non-residential structures**. The perpetual inventory method is used with the following depreciation rates. 17.6% for Machinery and equipment, and 1.75% for non-residential buildings and structures. The stock of capital is initially set to the Solow model steady state value of $I_t/(\delta + g)$, where $I$ is investment, $\delta$ is the depreciation rate and $g$ is the growth in investment during the period from 1870 to 2004. The post 1960 data are from OECD, *National Accounts, Vol. II*, Paris, *(NA)*. Before 1950 the following sources are used for the countries at which historical data are available**.** Canada. 1870-1900: Both types of investment are assumed to follow total non-residential investment in nominal prices deflated by the CPI. 1901-1925: 5-year average disaggregated into 1-year intervals using total non-residential investment deflated by CPI. Source: F. H. Leacy (ed.), 1983, *Historical Statistics of Canada,* Statistics Canada: Ottawa. United States. Angus Maddison, 1995, *Explaining the Economic Performance of Nations*, Edward Elgar. Japan: 1885-1988: A Maddison (1995) *op cit.*, Backdated to 1870 using the growth rate in total investment from Maddison (1995) *op cit*. 25.7% war damage to the 1945 capital stock is incorporated into the capital stock following Maddison (1995) *op cit*. Australia: 1863-1902: C. Clark, 1970, "Net Capital Stock," *Economic Record*, pp. 449-466. 1903-1950: M. W. Butlin, 1977, *A Preliminary Annual Database 1900/01 to 1973/74*, Research Discussion Paper 7701, Reserve Bank of Australia: Sydney. Belgium. M. van Meerten, 2003, *Capital Formation in Belgium, 1900-1995*, Leuven: Leuven University Press. Before 1900: The ratio of investment and GDP in 1900 multiplied by real GDP is used backdate the data to 1870. War damage correction: WWI. 15.5% of 1913 GDP spread out evenly between the years 1914-1917. WWII 7.1% spread out evenly on the years 1943-45. The correction for war damage follows van Meerteen, 2003, (see his footnote no. 39). Denmark: 1870-1950: K. Bjerke and Nils Ussing, 1958, *Studier Over Danmarks Nationalprodukt 1870-1950*, G. E. C. Gads Forlag: København. Finland. R. Hjerppe, 1989, *The Finnish Economy, 1860-1985*, Helsinki: Bank of Finland, Government Printing Centre. France. 1856-1895. Total investment deflated by industry prices. E. Chadeau, 1989, *l'Economie Nationale Aux XIX et XX Siecles*, Paris: Presses de l'Ecole normale Superieure. 1896-1914 and 1921-1938. J-J Carre P. Dubois and E. Malinvaud, 1975, *French Economic Growth*, Stanford: Stanford University Press. 1914-1921 and 1939-1949. Crude steel production adjusted. Liesner *op. cit.* War damage of 2% is assumed each year over the periods 1914-17 and 1942-1945 following Maddison, 1995, *op cit*. Germany: W. Kirner, 1968, *Zeitreihen fur das Anlagevermogen der Wirtschaftsbereiche in der Bundesreplublik Deutschland*, Deutsches Institut fur Wirtschaftsforschnung, Duncker & Humbolt: Berlin. The data are adjusted for war damage in the source. Non-residential buildings and structures 1850-1949. The following categories are added together: Land und Forstwirtschaft, Energiewirtschaft, Bergbau, Grundstoff- und Productionguter-industrie, Investeringsguterindustrie, Verbrauchenguterindustrie, Nahrings- und Genussmittel-industrie, Industrie Kleinbetr. und Handwerk, Baugewerbe, Handel, Eisenbahnen, Schifffahrt, Ubringer Verkehr, Nachr. ubermittlg, Kreditintitutionen und Vers. gew., Wohnungsvermietung, Sonst. Dienstleist., Strassen und Brukken, Wasser strassen und Hafen, and Ubrige staatl. Bereiche. Machinery and equipment 1926-1949. The same categories are added together as for investment in non-residential buildings and structures. 1870-1925: Scaled investment in machinery and equipment for Denmark, using the average over the period 1926-1930 as scaling factor. Italy. Istituto Centrale di Statistica, 1976, *Statistiche Storiche Dell'Italia 1861-*

*1975*. Residential building investment is included in investment in buildings. Only 10-year averages are available before 1945. The data are uniformly distributed within the 10-year intervals. Netherlands. 1800-1913: J-P Smits, E Horlings, and J L van Zanden, 2000, *Dutch GNP and its Components, 1800-1913*, Groningen, http://www.eco.rug.nl/ggdc/PUB/dutchgnp.pdf. The general investment deflator is used as deflator. 1913-60: Central Bureau voor de Statistiek, 2001, *Tweehondred Jaar Statistiek in Tijdreeksen, 1800-1999*, Centraal Bureau voor de Statistiek, Voorburg. 10% war damage is evenly spread out over the years 1943-1945. Norway. Statistisk Sentralbyraa, 1968, *Nasjonalregnskap*, Oslo. 1865-1930: The investment data are derived from capital stock and official depreciation rates using the following formulae for buildings and equipment, respectively: $I_t^{eq} = K_t^{eq} - K_{t-1}^{eq}(1-0.15)$ and $I_t^{st} = K_t^{st} - K_{t-1}^{st}(1-0.02)$ . 1930-1949: The data are interpolated from 1940 to 1945 using the algorithm which is suggested by V. Gomez and A. Maravall, 1994, "Estimation Prediction and Interpolation for Nonstationary Series with the Kalman Filter," *Journal of the American Statistical Association*, 89, 611-624. The general investment price deflator is used to adjust the *pre* 1940 data which are in 1938 prices, whereas the *post* 1945 data are in 1955 prices. Spain. A. Carrearas (ed), 1989, Estadisticas Historicas De Espana, Madrid: Fundacion Banco Exterior. 1850-1960: The growth rate in total investment is used to backdate investment in structures and machinery, respectively. Sweden. 1861-1949. O. Krantz and C. A. Nilsson, 1975, *Swedish National Product 1861-1970*, C. W. K. Gleerup. Investment in buildings include residential investment. Switzerland. Ritzmann-Blickenstorfer, 1996, *Historical Statistics of Switzerland*, Zurich: Chronos. The growth rate in total investment is used to backdate the data from 1922. UK. Maddison ,1995, *op cit*. An annual 3.5% war damage is corrected for in the estimates during the period 1943-45.

**Economy-wide real GDP.** The data are from OECD, *National Accounts*, after 1950. Before 1950: A. Maddison, 1995, *Monitoring the World economy 1820-1992*, OECD except for the following countries. Australia. B. Haig, 2001, "New estimates of Australian GDP 1861-1948/49," *Australian Economic History Review*, 41, 1-34. From 1939 onwards Maddison (1995) *op cit*. Finland. Hjerppe (1989) *op cit.* Italy. C. Bardini, A. Carreras, and P. Lains, 1995, "The National Accounts for Italy, Spain and Portugal," *Scandinavian Economic History Review* XLII, 115-146. Netherlands. Central Bureau voor de Statistiek, 2001, *op cit*. Norway. O. H. Grytten, 2004, "The Gross Domestic Product for Norway 1830-2003," in Chapter 6 in Ø Eitrheim, J. T. Klovland and J. F. Qvigstad (eds) *Historical Monetary Statistics for Norway 1819-2003*, Norges Bank Occasional Papers No 35, Oslo, 241-288. Spain. C. Bardini *et al*., 1995, *op cit*. Sweden. O. Johansson, 1967, *The Gross Domestic Product of Sweden and its Composition 1861-1955*, Stockholm: Almquist and Wiksell. Switzerland. Ritzmann-Blickenstorfer, 1996, *op cit*. C. H. Feinstein, 1976, *Statistical Tables of National Income, Expenditure and Output of the UK* 1855-1965, Cambridge: Cambridge University Press.