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**CONVERGENCE ACROSS
INDUSTRIALISED COUNTRIES
(1890-1989): NEW RESULTS USING
TIME SERIES METHODS**

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ABSTRACT

Augmented Dickey Fuller (ADF) and Kalman filter convergence tests are applied to annual GDPs per head for 16 industrialised countries from 1890 to 1989. Results favour convergence towards the US with a structural break following the Second World War. Estimates suggest that steady-states were higher after the war and that speeds of convergence are different across countries. The Kalman filter method dismissed the no convergence hypothesis more often than its ADF counterpart. This could explain the apparent contradiction in earlier empirical work on similar data sets (cross-section methods tended to favour convergence while time series methods could not dismiss no convergence.)

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Introduction

In this empirical study, time series methods of testing and measuring convergence are applied to long series for annual GDP per head for 16 industrialised countries from 1890 to 1989. The data set comprises the following countries: Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Italy, Japan, the Netherlands, Norway, Sweden, Switzerland, the United Kingdom and the United States.

The same set of countries was used before by Baumol (1986). In this influential paper, a regression of average growth rates from 1870 to 1979 on initial incomes produced a significant negative value. The author concluded that convergence was at work, and observed that results were different when additional countries were included.

Bernard and Durlauf (1991) considered a long series of GDP per head from 1900 to 1987 for all the aforementioned countries except Switzerland. They tested for the stationarity of the pairwise differences in GDP per head and concluded that there was a set of common factors that jointly determined output growth, but little evidence of convergence.

Other researchers have used data sets that are not very different from this one in what concerns included countries, but considered shorter time spans. Dowrick and Nguyen (1989) statistically compared growth rates for poorer and richer countries in the OECD in different periods from 1950 to 1985 and concluded in favour of convergence. An initial value cross-section regression including some conditioning variables reinforced their conclusion. Barro and Sala-i-Martin (1992a) and Mankiw, Romer and Weil (1992) considered 20 and 22 OECD countries, respectively, in both cases from 1960 to 1985. Also using initial value cross-section regressions, they concluded in favour of conditional convergence.

It might seem that time series tests are in contradiction to cross-sectional ones, the former not allowing the researcher to decide in favour of convergence. Considering previous results related by St. Aubyn (1995) and Hall and St. Aubyn (1995), it is likely that one of the following is true:

- industrialised countries are converging but cointegration-type tests fail to recognise that because they have low power, specially in the presence of structural breaks;

- only a part of the considered countries is converging. This is enough for cross-sectional initial value regressions to display a significant negative coefficient for the initial value, and would further explain the failure of a number of pair-wise cointegration tests.

Two time series methods (ADF cointegration tests and a Kalman filter test) are used here in testing for convergence across industrialised countries. These methods imply the choice of a benchmark country and the US seemed to be the natural choice, being the largest economy and the one that generally had the highest GDP per head during the whole period. Accordingly, the convergence tests are tests of convergence of a specific country towards the US.

Previous simulation work detailed in the two latter references gave ground to expect that the Kalman filter test would prove to be more powerful when applied to a situation that is likely to be characterized by structural change: the long time interval includes two

world wars and a couple of major economic crises.

When the no convergence hypothesis is rejected, the analysis goes further and estimates for both the speed of convergence and the steady-state levels are provided.

The structure of this paper is as follows.

The first section includes a description of the data set.

Definitions of convergence are given in the second section and related to previous literature on the subject. The third section summarises previous results and criticisms to different methods of measuring convergence. A presentation of the time series tests used in this paper follows.

Convergence tests to the US level (both Dickey-Fuller and Kalman filter) are presented and discussed in the fifth section. These tests considered the fifteen series of differences to the US for the whole time period (1890-1989) and also two different subperiods (1890-1939 and 1947-1989) for the restricted group of the G-7 countries.

The sixth section comprises estimates for the steady-state levels and speeds of convergence for the G-7 countries. Hypotheses that speeds and steady-state levels are the same in the two different subperiods and across countries are tested.

In the last section a reformulation of the cross-section initial value regressions procedure is presented and its results discussed, just before the general conclusion.

All simulation results and empirical estimates included in the paper were programmed by the author in Gauss and are available on request.

1. The data set

As mentioned above, real annual GDP per head data for 16 industrialised countries from 1890 to 1989 are used in this study. Data are listed in the appendix which also includes graphs plotting the differences in the logarithms of GDP per head between the G-7 countries and the US.

Except for Germany, GDP figures at 1985 US relative prices from 1890 to 1989 were computed after tables presented by Maddison (1991). Population figures came from the same source for years from 1890 to 1949 and from Summers and Heston (Penn World Tables, Mark 6, NBER gopher) for years from 1950 to 1989.

Maddison (1979) is the source for Germany GDP per head from 1890 to 1977. The figures from 1978 to 1989 came from the above mentioned sources. For all countries, series correspond to 1989 borders¹. Finally, note that German GDP per head is the GDP

¹Maddison (1989) includes GDP data adjusted for territorial change and population figures not adjusted for it. Since figures referring to population changes in years of changing borders are also given, population series were adjusted assuming that population in gained or lost territories grew at the same rate as in the rest of the country.

per head of West Germany.

2. What is convergence?

The meaning of "convergence" has to be clarified before one proceeds into testing. In this paper, it is assumed that GDPs per head of any two countries converge to each other if their difference becomes stationary in the long term. In more formal terms, consider two economic series X_t and Y_t . X_t and Y_t may represent GDPs per head, but also any other two series we are interested in. These two series converge if:

$$(X_t - Y_t) \rightarrow \epsilon_t \text{ as } t \rightarrow \infty, \quad (1)$$

where ϵ_t is a random variable obeying the following conditions:

$$E(\epsilon_t) = D_{xy}, \quad (2)$$

and

$$\text{Var}(\epsilon_t) = \sigma < \infty. \quad (3)$$

Equations (1.1) to (1.3) mean that the difference between the two series converges in probability to a third series that is stationary, having a constant mean D_{xy} and a constant variance σ .

It should be clear that although X_t converges to Y_t in economic terms, it does not converge in statistic terms. Nevertheless, a statistical meaning of convergence is used in the economic definition of the same term.

To make my definitions compatible with previous ones presented elsewhere (e.g. Barro and Sala-i-Martin (1995)) economic convergence is:

- a) *point wise*, if $\text{Var}(\epsilon_t) = 0$;
- b) *unconditional*, if $D_{xy} = 0$;
- c) *conditional*, if $D_{xy} \neq 0$.

The definitions above encompass the "beta-convergence" concept proposed by Barro and Sala-i-Martin (1992a, 1995). In their work, series are assumed to converge to their steady-state level at an annual constant rate. If the steady-states are the same, "beta-convergence" is unconditional. If they are different but grow at the same rate, "beta-convergence" is conditional. The definitions presented earlier are more general because they do not imply a constant rate of convergence and therefore differences between series are not necessarily stationary from the beginning.

3. Time series and cross sections methods

Very different methods have been proposed to test and measure convergence of economic series, particularly GDPs per head. It is beyond the scope of this paper to survey them in any detail and this has been done elsewhere². Here, I stick to the main conclusions that arise from some previous work.

Tests and methods of measuring convergence can be divided into two main groups: cross section and time series methods. The former test for convergence of a group of more than two series. The latter use two series at a time only.

Cross section methods include the analysis of the time series of a dispersion measure, "initial value" or "Barro" regressions and their derivations and the estimation of Markov transition matrices. Although they have problems of their own, these methods suffer from a common drawback: it becomes difficult to accommodate the possibility of limited convergence or the existence of different clubs. These two situations are characterised by cross section variation. By limited convergence it is understood that only a subset of series (e. g. countries' GDPs) converge to one leading series. When there is more than one club, there is more than one leading series and each of the remaining series is attracted (converges to) one and only one of them. Detailed results using Monte Carlo methods that support these assertions can be found in St. Aubyn (1995) and Hall and St. Aubyn (1995).

Time series tests for convergence usually take the difference between two series and analyse its properties. These tests share a common property: it becomes easier to allow for convergence clubs or limited convergence. For example, if you suppose that country A belongs to the same club as country B, simply test for convergence of series A to B. The more popular time series approach to convergence is to test this difference for stationarity using, for example, a Dickey-Fuller statistic. This approach is not completely satisfactory, in the sense that convergence, according to the definitions from section 1, does not necessarily imply stationarity of the differences. For example, Hall, Roberston and Wickens (1992) give the following example: two series are completely independent from each other, and, from a certain point in time, become exactly equal. These series would converge, but would not pass the stationarity test.

In order to allow for a convergence process that starts occurring after the beginning of the period being considered, Hall, Roberston and Wickens (1992, 1993) propose the use of the Kalman filter. Monte Carlo experiments reported by St. Aubyn (1995) and by Hall and St. Aubyn (1995) provide some evidence that this method is more powerful than the Dickey-Fuller one when there is a structural break in the convergence process.

These two methods used here and therefore a brief description of each one follows.

²See Sala-i-Martin (1994) and de la Fuente (1995) for a survey of cross-section methods and their results. Hall and St. Aubyn (1995) compare both cross section and time series methods using artificial data. The same approach is taken by St. Aubyn (1995), where a survey of different methods is included.

4. Time series convergence tests

4.1 Dickey-Fuller and Augmented Dickey-Fuller tests

Dickey-Fuller tests for convergence are stationarity tests for the differences between each country GDP and the US GDP.

Equation (4) was estimated using OLS. d_t is the difference between the country which is being discussed and the US GDPs per head.

$$d_t - d_{t-1} = b_1 + b_2 \cdot d_{t-1} + \sum_{j=1}^l b_{2+j} \cdot (d_{t-j} - d_{t-j-1}) + \epsilon_t. \quad (4)$$

The number of lags denoted by l was chosen so that residuals would not display significant autocorrelation or non normality³. A Lagrange multiplier test for autocorrelation and the Bera-Jarque normality test were used for this effect⁴. In some cases, some dummy variables were introduced in equation (4) to take account of wars and economic crises. These dummy variables are of the form:

$$DU_{yt} = \begin{cases} 1, & \text{if } t=y, \\ 0, & \text{otherwise.} \end{cases} \quad (5)$$

Usually, the dummies were introduced to account for the big shocks that correspond to the two world wars years; they are listed by country in Table XIII (in the appendix.)

Table I

Critical values for the DF and ADF t-statistic
5 % and 1% significance levels

significance level	t=43	t=50	t=100
5 per cent	-2.93	-2.92	-2.89
1 per cent	-3.59	-3.58	-3.50

Source: MacKinnon (1991).

³In some cases there was no need to introduce the lagged dependent variable in the right-hand side of the equation.

⁴See Cuthbertson, Hall and Taylor (1992) for a presentation of these tests.

If equation (4) does not include lagged values of Δd_t , the test is called a "Dickey-Fuller" (DF) test. If l is one or greater, the test becomes an "Augmented Dickey-Fuller" (ADF) one. In both cases the statistic of concern is the t-statistic for the b_2 coefficient. Under the null hypothesis of non-stationary, this statistic is not normally distributed. The relevant critical values are reproduced in Table I⁵.

4.2 Kalman filter tests

The Kalman filter test used here was described in more detail in St. Aubyn (1995) and is a version of a convergence test proposed by Hall, Robertson and Wickens (1993). In the following formulation, d_t is the difference between the series:

$$d_t = \alpha_t + \epsilon_t, \quad (6)$$

$$\alpha_t = \alpha_{t-1} + \mu_t, \quad (7)$$

$$\epsilon_t \sim N(0, \sigma^2), \quad (8)$$

$$\mu_t \sim N(0, \Omega_t), \quad (9)$$

$$\Omega_t = \phi^2 \Omega_{t-1}, \quad (10)$$

$$\Omega_0 = \Upsilon^2. \quad (11)$$

Although the noise variance (σ^2) is constant through time, the variance of μ may display a declining pattern. If ϕ is less than 1, this variance tends to 0 in the long run, meaning that the two series are converging, their difference becoming a stationary variable.

In this model written in state-space form equation (6) is the measurement equation and equation (7) is the state one. The likelihood function can be constructed using the Kalman filter. The maximum likelihood (ML) estimates for the parameters are obtained maximizing it.

⁵Values were taken from MacKinnon(1991).

The null hypothesis of no convergence implies that $\phi=1$. Therefore, the proper test for convergence is: $H_0: \phi=1$ against $H_a: \phi<1$. The implementation of this test requires the distribution of (some function of) ϕ under the null. The distribution of the following was tabulated after 1000 replications:

$$T(\phi_{ML}) = \frac{\phi_{ML} - 1}{\sqrt{(h^{-1})_{22}}} \quad (12)$$

In equation (12), $(h^{-1})_{22}$ is the second element in the diagonal of the inverse of Hessian matrix. The tabulation is reproduced in Table II.

Table II

Critical values for the $T(\phi_{ML})$ statistic

%	t-value
0.5	-3.702
1	-3.479
5	-2.479
10	-1.970
50	-0.059
99	3.348
99.5	3.529

5. The results

5.1 Results from Dickey-Fuller and Augmented Dickey-Fuller tests

Three different periods were considered: the period that goes from 1890 to 1989 and two subperiods chosen to exclude the Second World War. The first subperiod starts in 1890 and ends in 1939 and the second one goes from 1947 to 1989. The countries that constitute the "G-7 group" (Canada, France, Germany, Italy, Japan, the United Kingdom and the United States) were analysed in more detail. They were the only ones considered in the two sub-periods⁶.

⁶The US is not included in the table because differences in respect to that country GDP are considered.

Dickey-Fuller tests results are summarised in Table III. Values within brackets correspond to the number of lags (given by l) in equation (4).

Table III

Dickey-Fuller convergence to the US tests

Country	1890-89	1890-1939	1947-1989
Canada	-0.5943 (3)	-2.404 (0)	-0.3441 (0)
France	-4.060** (0)	-3.980** (0)	-1.930 (2)
Germany	-2.720 (1)	-2.630 (0) -3.433** (0) until 1937	-3.709** (1)
Italy	-2.359 (2)	-2.036 (0)	-3.230** (0)
Japan	-0.7851 (0)	-1.104 (0)	-3.597** (0)
United Kingdom	-2.316 (0)	-1.930 (0)	-1.838 (0)
Australia	-3.063(0)*		
Austria	-2.640(1)		
Belgium	-5.266**(4)		
Denmark	-2.602(1)		
Finland	-0.4153(0)		
Netherlands	-3.301* (0) from 1900		
Norway	-0.780 (1)		
Sweden	-0.809 (1)		
Switzerland	-3.112* (1)		

* "No convergence" rejected at the 5 per cent confidence level;

** "No convergence" rejected at the 1 per cent confidence level.

More often than not, the "no convergence" hypothesis can not be dismissed. Considering the period from 1890 to 1989, this hypothesis is rejected for five countries (in sixteen) at the five or one percent confidence level. The five countries are: Australia, Belgium, France, the Netherlands and Switzerland. Among the G-7 countries, and considering the period before the Second World War, "no convergence" is only dismissed in the French and German cases. In the post-war period, the null hypothesis is rejected for Germany, Italy, and Japan, but not for France, Canada or the United Kingdom.

5.2 Results using the Kalman filter

Table IV displays the results for the $T(\phi_{ML})$ statistic using the Maddison data. Again, some

dummies of the form given by (5) were introduced in the measurement equation⁷.

Table IV

Kalman filter convergence to the US tests

Country	1890-1989	1890-1939	1947-1989
Canada	-7.212**	1.035	-1.710
France	-7.983**	-0.300	-4.693**
Germany	-3.723**	0.709	-6.469** (from 1950)
Italy	-6.432**	-0.391	-5.292**
Japan	-3.640**	3.010	-4.108**
United Kingdom	-6.464**	0.120	-3.090*
Australia	-9.184**		
Austria	-3.241*		
Belgium	-6.162**		
Denmark	-5.967**		
Finland	-3.656**		
Netherlands	-7.603** (from 1900)		
Norway	-3.650**		
Sweden	-4.471**		
Switzerland	-4.078** (from 1899)		

* "No convergence" rejected at the 5 per cent confidence level;

** "No convergence" rejected at the 1 per cent confidence level.

For the longer period, the no convergence hypothesis could be dismissed for all countries considered, at least at the 5 % confidence level. This was not the case for the Dickey-Fuller test. It was shown in Hall and St. Aubyn (1995) that the Kalman filter test tended to be more powerful when convergence does not work from the very beginning of the sample period. This can well be the case here.

On the other hand, Dickey-Fuller tests seem to be more powerful in dismissing convergence when the first sub-period is considered. With this second method, the no

⁷The residuals for Japan and Canada in the period from 1947 to 1989 did not pass the normality test. See Table XIV for a list of these dummies.

convergence hypothesis was never dismissed. According to the simulation results described in St. Aubyn (1995), this could be due to the fact that the countries considered were already close to their steady-state in 1890. Results for the post-war period are stronger: no convergence is rejected for all the G-7 countries, except for Canada. This last result is probably due to the fact that Canada was the country closest to the US after the Second World War (time series methods have low power when the difference between two series starts close to the steady state.)

5.3 Summary of results

It can be concluded that the sixteen countries under analysis were converging from 1890 to 1989. The post-war period (1947-1989) was probably the time where that convergence process was more evident. Nevertheless, the failure to detect convergence in the early period (1890-1989) can be due to two reasons: either countries started converging somewhere between 1890 and 1939 or countries were already close to their steady-state in the beginning of the period.

For France and Germany it was possible to reject the no convergence hypothesis even in the first sub-period. It must be stressed that both ADF and the Kalman filter methods test for conditional convergence, so that countries are not necessarily converging to the same level of income. Take the case of France, for example. The no convergence hypothesis was rejected for the whole period and for each subperiod but Figure 4 (in the appendix) suggests that the steady-state level of French income is not equal to the US one. Before the Second World War, and excluding the First War and the 1929 crisis, there was no asymptotic approximation towards the US level. After the forties, and following the big Second World War shock, there is a marked tendency to an approximation to US levels. Nevertheless, this approximation seems to have stopped in the seventies, suggesting that the steady-state level was attained by then.

In the following section, estimates for the different steady-states across countries are provided. Also, the hypothesis that the steady-state is different in the two subperiods is considered and tested.

6. Estimating the speed of convergence and the steady-state

6.1 The estimation method

Consider the model described by equations (13) and (14):

$$d_t = d_{ss} + b_t \cdot (d_{t-1} - d_{ss}) + \epsilon_t, \quad (13)$$

$$b_t - \bar{b} = a (b_{t-1} - \bar{b}) + \mu_t, \quad (14)$$

where a is between -1 and 1. ϵ_t and μ_t are i.i.d. normal disturbances.

b_t is a time-varying speed of convergence. Nevertheless, and considering that $|a| < 1$, it

tends to return to its "long run" value, given by $\bar{b}$. This is a case of a "return to normality" model.⁸

Equations (13) and (14) are the measurement and transition equations in a state-space representation of the return to normality model. The concentrated log-likelihood can be written as an implicit function of the relevant hyperparameters and maximized using numerical methods. Here, the estimated hyperparameters are the steady-state level d_{ss} , the long run speed of convergence $\bar{b}$, the autoregressive parameter for the short-run speed of convergence a , and the variance in the transition equation (as a ratio to the variance in the measurement equation.) The inverse of the Hessian matrix is an estimate for the variance-covariance matrix of the hyperparameters and was used in the construction of the t-tests presented below.

6.2 Results for the period from 1890 to 1989

Estimates for the steady-state and the speed of convergence are presented in Table VI⁹. Numbers inside brackets are t-statistics.

Table V

Steady-state as a percentage of the US
1890-1989

	steady-state (% of US)
France	69.8
Germany	61.8
Italy	63.3
United Kingdom	73.3

The speed of convergence and the steady-state estimates were not statistically significant in two cases: Japan and Canada. One possible interpretation can be applied to both countries. If convergence started after 1890 it is very likely that Dickey-Fuller-type tests do not detect it. Moreover, and according to earlier simulation results, it is very likely in that case that convergence is detected by a Kalman filter test. This was the case for both countries: from Table III and Table IV it can be noted that Dickey-Fuller t-statistics were not significant while the $T(\phi_{ML})$ statistic was significantly smaller than zero in both cases.

France, Germany, Italy and the United Kingdom all display speeds that are higher than zero. Their steady-states are all significantly smaller than zero. This shows that these

⁸See Harvey (1989).

⁹The t-statistics in the first column of the table are equal to the ones presented before as "Dickey-Fuller tests".

countries were converging conditionally towards the United States. In the long run, the difference between the logs of incomes per head is a stationary variable with a non-zero mean.

Incomes per head were taken in log form. Let Y_{us}^s and Y_i^s denote the steady-state levels for the US and country i incomes, taken in original units. Since:

$$\ln(Y_i^s) - \ln(Y_{us}^s) = SS_i \Rightarrow \frac{Y_i^s}{Y_{us}^s} = \exp(SS_i), \quad (15)$$

it is possible to express the steady-state values presented in Table VI as a percentage of US GDP per head. This is done in Table V.

Table VI
Speed of convergence and steady-state
Return to normality model
1890-1989

	speed	steady-state	KF log likelihood
Canada	0.004 (-0.397)	1.403 (0.347)	345.5
France	0.127 (-6.010)	-0.419 (-12.41)	291.6
Germany	0.077 (-2.918)	-0.400 (-6.739)	292.1
Italy	0.052 (-2.315)	-0.394 (-4.321)	300.3
Japan	0.005 (-0.602)	2.420 (0.490)	278.7
United Kingdom	0.069 (-2.532)	-0.298 (-4.190)	284.6

6.3 Are the estimates stable through time?

The Second World War was a tremendous shock to the G-7 GDPs, as can be seen directly from the graphs. As mentioned before, it was necessary to introduce some dummies to account for this shock and bring the residuals back into normality.

These shocks and the data themselves suggest that different patterns of convergence could

have existed before and after the Second World War¹⁰.

To test for stability, the sample was divided into two parts. The first one goes from 1890 to 1946. The second from 1947 to 1989.

First, an unrestricted model that allows for different parameters in the two subperiods was estimated using the Kalman filter. This model is described by the following equations:

$$d_t = d_{ss} + \Delta d_{ss} \cdot D_{1947} + b_t \cdot (d_{t-1} - (d_{ss} + \Delta d_{ss} \cdot D_{1947})) + \epsilon_t, \quad (16)$$

$$b_t - (\bar{b} + \Delta \bar{b} \cdot D_{1947}) = (a + \Delta a \cdot D_{1947}) (b_{t-1} - (\bar{b} + \Delta \bar{b} \cdot D_{1947})) + \mu_t, \quad (17)$$

$$\text{Var}(\mu_t) = (Q + \Delta Q \cdot D_{1947}) \cdot \text{Var}(\epsilon_t). \quad (18)$$

$$DU_{1947} = \begin{cases} 1, & \text{if } t > 1946, \\ 0, & \text{otherwise.} \end{cases} \quad (19)$$

There are eight hyperparameters in this unrestricted model:

- the steady-state in the period 1890-1946;
- the change in the steady-state from the first period to the second one (1947-1989);
- the speed of convergence in the first period;
- the change in speed from the first to the second period;
- the autoregressive parameter in the transition equation in the first period;
- the change in the autoregressive parameter;
- the variance in the transition equation (as a proportion of the variance in the measurement equation);
- the change in the variance in the transition equation.

The restricted model determines that four of these parameters are equal to zero (the changes), so that speeds, steady-states and autoregressive parameters are the same in both periods. This is the model described by equations (13) and (14) and its results were already discussed. The same dummies were introduced in the restricted and unrestricted models (see Table XV, in the appendix.)

A likelihood ratio test was performed to check the validity of the four restrictions. If the restrictions are valid, the following statistic is asymptotically distributed as a chi-square with four degrees of freedom:

¹⁰This is a hypothesis that Maddison (1989) defends.

$$LR = 2 \cdot (\ln(L_u) - \ln(L_r)) .$$

(20)

In equation (20) $\ln(L_u)$ is the natural logarithm of the maximum likelihood for the unrestricted model and $\ln(L_r)$ is the same quantity for the restricted model.

Table VII displays some results for the unrestricted model. Values within brackets are t-values. In all cases the hypothesis of no structural change was rejected at less than one percent significance level. With the exception of Canada, the speed of convergence was always found to be positive.

Table VII

Return to normality model
Unrestricted version
1890-1989

	steady-state 1890-1946	change in steady-state 1947-1989	convergence speed 1890-1946	change in speed 1947-1989	log likelihood
Canada	1.193 (0.622)	-0.13 (-0.070)	0.005 (0.9660)	-0.00 (-0.143)	355.7
France	-0.53 (-28.00)	0.29 (4.40)	0.293 (5.79)	-0.219 (-4.147)	305.1
Germany	-0.54 (-9.76)	0.28 (4.689)	0.112 (3.627)	-0.003 (0.10)	310.3
Italy	-0.83 (-18.58)	0.56 (5.219)	0.119 (2.407)	-0.06 (1.138)	308.2
Japan	-1.34 (-30.46)	1.44 (6.574)	0.166 (4.733)	-0.122 (-3.209)	302.8
United Kingdom	-0.33 (-3.983)	-0.018 (-0.200)	0.085 (3.5530)	0.069 (0.78)	299.1

The two steady-states are compared in Table VIII and presented as a percentage of US GDP (Canada was excluded.)

For France, Germany, Italy and Japan there was a significant increase in the steady-state. The change for this last country was dramatic: the steady-state for the post-war period is estimated to be above the US level. The United Kingdom was the only country for which the steady-state did not increase. It was also the country with the highest steady-state in the pre-war period among the five considered in the table.

The speed of convergence suffered significant decreases in France and Japan. In all the other countries the corresponding t-values were not sufficiently high in absolute value in order to dismiss the no change hypothesis.

Table VIII

Steady-state as a percentage of the US
1890-1946 and 1947-1989

	steady-states:	
	1890-1946	1947-1989
France	58.9	78.7
Germany	58.3	77.1
Italy	43.6	76.3
Japan	26.2	110.5
United Kingdom	71.9	70.6

6.4 Convergence after the Second World War

In the last section some estimates using the Kalman filter and referring to the after war period were presented. Here, results using OLS are discussed and two hypothesis are examined. First, the equality of speeds, and second, the equality of steady-states across countries are tested.

Both tests are likelihood ratio tests. This kind of tests always imply the estimation of both the restricted and unrestricted models.

The period from 1950 to 1989 was considered. The following equation describes the general model:

$$d_{it} - d_{i,t-1} = b_{i1} + b_{i2} \cdot d_{i,t-1} + \sum_{j=1}^3 b_{i,2+j} \cdot (d_{i,t-j} - d_{i,t-j-1}) + \epsilon_{i,t} \quad (21)$$

Five countries were contemplated: France, Germany, Italy, Japan and the United Kingdom, and, as before, differences from the US GDP were taken. Canada was excluded because the unit root hypothesis could not be dismissed.

The number of lags in equation (21) was sufficiently high to allow the residuals not to display any correlation and to pass the Bera and Jarque normality test in each of the considered series.

The unrestricted model was estimated by maximum likelihood¹¹. The log-likelihood

¹¹This is equivalent to the estimation of each of the five single equations using OLS.

function to be maximised is:

$$\log L(b, \sigma) = -\frac{1}{2} \log(2\pi) - \frac{1}{2} \log |\Theta| - \frac{1}{2} \sum_{i=1}^5 \{ (Y_i - X_i' b_i)' \Theta_i^{-1} (Y_i - X_i' b_i) \}, \quad (22)$$

where

$$Y_i = \begin{pmatrix} d_{i5} - d_{i4} \\ \dots \\ d_{iT} - d_{i,T-1} \end{pmatrix}, \quad X_i = \begin{pmatrix} 1 & d_{i4} & d_{i4} - d_{i3} & \dots & d_{i2} - d_{i1} \\ \dots & \dots & \dots & \dots & \dots \\ 1 & d_{iT} & d_{iT-1} - d_{i,T-2} & \dots & d_{i,T-3} - d_{i,T-2} \end{pmatrix}, \quad \Theta_i = \sigma_i^2 I,$$

$$b_i = \begin{pmatrix} b_{i1} \\ \dots \\ b_{i5} \end{pmatrix}, \quad \sigma = \begin{pmatrix} \sigma_1 \\ \dots \\ \sigma_5 \end{pmatrix}, \quad b = \begin{pmatrix} b_1 \\ \dots \\ b_5 \end{pmatrix}.$$

The equality of speeds restriction is expressed as follows:

$$b_{12} = b_{22} = \dots = b_{52} = b_{R2}. \quad (23)$$

The corresponding restricted log-likelihood function is expressed as in (22) but this time with:

$$b_{NR} = (b_{11} \ b_{13} \ b_{14} \ b_{15} \ | \ \dots \ | \ b_{51} \ b_{53} \ b_{54} \ b_{55})',$$

$$b_i = \begin{pmatrix} b_{i1} \\ b_{R2} \\ \dots \\ b_{i5} \end{pmatrix}, \quad b = \begin{pmatrix} b_{R2} \\ - \\ b_{NR} \end{pmatrix}.$$

Table IX contains estimates for the restricted and unrestricted speeds.

Values within brackets are t-values and were computed from the inverse of the Hessian matrix. Table IX suggests that speeds are different across countries. The value for Britain is ten times greater than the value for Japan. In fact, this is the conclusion drawn from the likelihood test, summarised in Table X. Nevertheless, Japan is converging to a steady-state that is higher than the British one (and possibly higher than the US one.) Supposing that British GDP is converging at a high rate to its steady-state (32 percent per year); approximately a third of a shock that deviates it from its long run value as a percentage of US GDP is eliminated within one year. In practice, that means that British GDP per head is always not very far from its steady-state level (estimated as 71.1 percent of the

US value.)

Table IX
Speed of convergence estimates
1950-1989

	unrestricted version	restricted version
France	0.091 (3.441)	0.0641 (8.563)
Germany	0.136 (4.283)	0.0641 (8.563)
Italy	0.086 (3.464)	0.0641 (8.563)
Japan	0.033 (2.461)	0.0641 (8.563)
United Kingdom	0.319 (3.578)	0.0641 (8.563)

The fact that Japan is converging to a higher steady-state (estimated to be 104.1 percent of US GDP) at a lower rate (3.3 percent per year) implies that Japanese growth rates are generally higher than US ones. This happens because Japan is starting from a lower level than the US. Once the Japanese steady-state is reached, one can expect Japan growth rates to become similar to the US ones.

Table X
Log-likelihood tests
Same speed and same steady-states across countries
1950-1989

unrestricted log likelihood	restricted log likelihood (same speed)	χ^2 statistic significance level (same speed)	restricted log-likelihood (same steady- state)	χ^2 statistic significance level (same steady- state)
679.80	667.75	0.0	674.88	0.080

The LR statistic for the equality of speeds test takes the value 24.1 ($=2 \cdot (679.8 - 667.75)$),

see Table X.) Its p-value is virtually zero.

Consider now the equality of steady-states hypothesis. This restriction is given by:

$$\frac{b_{11}}{b_{12}} = \frac{b_{21}}{b_{22}} = \dots = \frac{b_{51}}{b_{52}} = b_s. \quad (24)$$

Again the corresponding restricted log-likelihood function is expressed as in (22), in this case with:

$$b_i = \begin{pmatrix} b_s, b_{i2} \\ b_{i2} \\ \dots \\ b_{i5} \end{pmatrix}, \quad b_{NR} = (b_{12} \dots b_{15} \mid \dots \mid b_{52} \dots b_{55}), \quad b = \begin{pmatrix} b_s \\ - \\ b_{NR} \end{pmatrix}.$$

Results from the restricted and unrestricted models are presented in Table XI. As usual, values within brackets are t-values.

Table XI
Steady-state estimates
1950-1989

	unrestricted version	restricted version
France	-0.246 (-4.023)	-0.302 (-13.529)
Germany	-0.282 (-9.050)	-0.302 (-13.529)
Italy	-0.284 (-3.358)	-0.302 (-13.529)
Japan	0.0405 (0.138)	-0.302 (-13.529)
United Kingdom	-0.341 (-28.78)	-0.302 (-13.529)

It becomes apparent that steady-state values are not very different across countries, particularly if Japan is excluded. In Table XII these values are expressed as a percentage of the US GDP per head. French, German, Italian, and British values are all close to three quarters of the American figure.

Table XII

Steady-state estimates as percentage of US
1950-1989

	steady-state
France	78.2
Germany	75.4
Italy	75.3
Japan	104.1
United Kingdom	71.1

The formal likelihood test result can be read from Table X. The restricted log-likelihood is sufficiently close to the unrestricted one to allow the non-rejection of the restriction at the eight percent confidence level. If Japan had been excluded from the set of countries this last level would probably be higher.

7. Initial value regressions reconsidered

It must be remembered that "initial value" or Barro regressions are cross-section regressions of the growth rate on the initial level values. These regressions often include some conditioning variables to proxy for different steady-state levels. It has been argued before that these regressions are not an adequate test for convergence. Results from this type of regressions are interpreted here *after* performing other convergence tests. Only series that passed the convergence test are included.

The first regression was an "unconditional" regression, a simple regression of growth rates on initial values:

$$\begin{aligned}
 g_{i,50-89} &= 0.0654 - 0.0232 y_{i,50}, \\
 &\quad (18.325) \quad (-9.3637) \\
 R^2 &= 0.945, \quad \hat{\sigma} = 0.00326, \quad (25) \\
 \hat{\beta} &= 0.059.
 \end{aligned}$$

Six countries were included: France, Germany, Japan, Italy, the United Kingdom and the United States. $g_{i,50-89}$ is the average growth rate of country i from 1950 to 1989 and $y_{i,50}$

is the GDP per head for country i in 1950. Values within brackets are t-statistics. $\hat{\beta}$ is an estimate of the speed of convergence derived from the coefficient on the initial value.

Equation (25) imposes the same steady-state level across the five countries. In the last section, this hypothesis could not be rejected at the eight percent confidence level. This is probably why results are highly significant (t-values are very high in absolute terms, even allowing for the low number of degree of freedom.) Results can be improved if *estimates* for each country steady-state are included as an explanatory variable, as in the following estimated equation:

$$g_{i,50-89} = 0.0676 - 0.0224 y_{i,50} + 0.0177 \hat{s}_i$$

$$(72.10) \quad (-35.77) \quad (7.81)$$

$$R^2 = 0.998, \quad \hat{\sigma} = 0.000815, \quad (26)$$

$$\beta = 0.052.$$

The steady-state estimates were taken from (the US value equals zero). All the t-statistics are highly significant. As expected, the higher the steady-state the higher the growth rate is.

There are some important differences in the approach followed in this section and the Barro and Sala-i-Martin (1992a, 1992b, 1995) approach. Firstly, initial value regressions are not being used as convergence tests. Secondly, the conditioning variables are not proxies for different steady-states. Estimates for the different steady-states were used as conditioning variables, instead. These estimates were obtained from time series methods.

Conclusion

Convergence of GDP per head to US levels for 15 industrialised countries from 1890 to 1989 was formally tested using two different methods: Dickey-Fuller-type tests and Kalman filter tests. Kalman filter tests were more powerful in dismissing the "no convergence hypothesis". In fact, the last method rejected this hypothesis in every case.

When the period was split into two subperiods of more or less the same length and which excluded the Second World War years (1890-1939 and 1947-1989) results were different. Considering only Canada, France, Germany, Italy, Japan and the United Kingdom, it is possible to see that the no convergence hypothesis was dismissed in every case in the more recent period (except for Canada), but only for Germany and France in the first period. One possible explanation is that convergence started to take place somewhere between 1890 and 1939, was disrupted by the Second World War and resumed soon after it.

On the whole, the Kalman filter results give strength to earlier results using cross-section methods and favouring convergence across industrialised countries as mentioned in the introduction to this paper. The possibility that tests using cointegration techniques (also used here) did not dismiss the no convergence hypothesis because they were not robust enough in the presence of time-varying convergence is also reinforced.

Some direct attempts were presented to measure the steady-state and the speed of convergence for each of the G-7 countries (excluding the US, always used as a benchmark.) Also, the estimated steady-state levels before and after the war were

compared.

Steady-state levels are generally higher after the war, except for the United Kingdom and Canada. Equality of steady-state levels after the war (1950-1989) at a level of roughly three quarters of the US one could not be rejected, even if Japan appears as an outlier. The estimated steady-state for this country was somewhat higher than the US level.

Estimates for the speed of convergence were disparate across countries and time. Equality of speeds in the post-war period was rejected and estimated values varied from 0.03 (Japan) to 0.319 (United Kingdom.) A correct interpretation of these figures has to take the different steady-state levels into account.

Appendix

Table XIII
 Convergence to the US
 Dickey-Fuller tests
 Years with dummy variables

Country	1890-89	1890-1939	1947-1989
Canada	1918-19, 1931, 1943, 1946-47	none	1951, 1956, 1974-75
France	1918, 1940-46	1918	none
Germany	1923-24, 1945-46	1919, 1923	none
Italy	1897, 1919, 1941-46	none	none
Japan	1942-46	none	none
United Kingdom	none	none	none
Australia	none		
Austria	1917-19, 1940-45		
Belgium	1918-19, 1931, 1943, 1946-47		
Denmark	1914, 1918, 1940-46		
Finland	1918-19, 1940-46		
Netherlands	1918-19, 1940-46		
Norway	1932, 1946		
Sweden	1946		
Switzerland	none		

Table XIV

Convergence to the US

Kalman filter tests

Years with dummy variables

Country	1890-89	1890-1939	1947-1989
Canada	1946-47	none	1951, 1956, 1974-1976
France	1940-45	1918	1949, 1970, 1982, 1984
Germany	1923, 1940-45	1923	1970, 1982
Italy	1941-46	none	1974, 1980, 1982, 1984
Japan	1932, 1942-46	1894, 1932	none
United Kingdom	1932, 1946	none	none
Australia	1946		
Austria	1945-46, 1948-49		
Belgium	1918, 1940-45		
Denmark	1940-45		
Finland	1918-19, 1942, 1946		
Netherlands	1940-46		
Norway	1930, 1932, 1940-46		
Sweden	1946-47		
Switzerland	1941-47		

Table XV
Dummies in the return to normality model

	dummies in:
Canada	1918-19, 1931, 1943, 1946-47
France	1918, 1940-46
Germany	1923, 1940-46
Italy	1897, 1919, 1936, 1941-46
Japan	1932, 1938, 1942-46
United Kingdom	none

Table XVI
GDP per head in the G-7 countries (1870-1989)
(1985 US 1000 relative dollars)

Year	Canada		France	Germany	Italy	Japan	UK	U.S.A.
1870	1.330	1.571	1.300	1.214	0.618	2.682	2.254	
1871	1.357	1.604	1.285	1.219		2.812	2.299	
1872	1.326	1.778	1.368	1.193		2.790	2.242	
1873	1.421	1.657	1.414	1.232		2.828	2.388	
1874	1.431	1.854	1.504	1.224		2.846	2.322	
1875	1.383	1.902	1.494	1.254		2.886	2.384	
1876	1.284	1.774	1.468	1.218		2.883	2.361	
1877	1.345	1.825	1.441	1.208		2.879	2.380	
1878	1.288	1.793	1.492	1.216		2.860	2.427	
1879	1.395	1.693	1.439	1.224		2.818	2.674	
1880	1.435	1.803	1.412	1.277		2.923	2.929	
1881	1.606	1.878	1.436	1.185		2.999	2.957	
1882	1.648	1.946	1.451	1.279		3.062	3.065	
1883	1.628	1.919	1.521	1.265		3.062	3.062	
1884	1.745	1.883	1.545	1.264		3.044	3.051	
1885	1.626	1.852	1.572	1.277	0.683	3.004	2.999	
1886	1.634	1.852	1.570	1.325	0.738	3.026	3.023	
1887	1.676	1.868	1.616	1.354	0.763	3.121	3.093	
1888	1.760	1.900	1.662	1.340	0.723	3.235	3.012	
1889	1.758	1.894	1.691	1.272	0.753	3.382	3.134	
1890	1.846	1.947	1.725	1.345	0.813	3.369	3.115	
1891	1.887	1.994	1.703	1.329	0.768	3.341	3.184	
1892	1.863	2.045	1.759	1.246	0.814	3.233	3.424	
1893	1.823	2.044	1.827	1.295	0.810	3.203	3.195	
1894	1.897	2.118	1.852	1.270	0.899	3.386	3.043	
1895	1.874	2.045	1.915	1.281	0.903	3.461	3.347	
1896	1.809	2.120	1.954	1.309	0.844	3.571	3.219	
1897	1.985	2.072	1.978	1.243	0.853	3.583	3.462	
1898	2.042	2.184	2.031	1.345	1.003	3.721	3.471	
1899	2.199	2.283	2.073	1.367	0.918	3.838	3.721	
1900	2.291	2.323	2.131	1.436	0.948	3.775	3.757	
1901	2.447	2.245	2.051	1.519	0.969	3.740	4.100	
1902	2.608	2.190	2.068	1.466	0.907	3.803	4.060	
1903	2.630	2.253	2.151	1.525	0.958	3.731	4.180	
1904	2.592	2.283	2.204	1.527	0.954	3.722	4.050	
1905	2.775	2.320	2.219	1.600	0.929	3.799	4.263	
1906	3.013	2.334	2.255	1.647	1.042	3.892	4.665	
1907	3.025	2.453	2.321	1.818	1.065	3.932	4.652	
1908	2.799	2.450	2.328	1.847	1.059	3.739	4.189	
1909	2.999	2.515	2.345	1.974	1.045	3.791	4.608	
1910	3.179	2.400	2.396	1.884	1.047	3.875	4.559	
1911	3.311	2.569	2.447	1.988	1.089	3.958	4.634	
1912	3.474	2.772	2.527	1.992	1.112	4.001	4.776	
1913	3.514	2.728	2.607	2.072	1.114	4.136	4.868	
1914	3.286	2.534	2.194	2.054	1.066	4.141	4.408	
1915	3.420	2.543	2.080	2.271	1.134	4.445	4.467	
1916	3.713	2.712	2.107	2.536	1.294	4.525	5.013	
1917	3.816	2.332	2.119	2.666	1.327	4.556	4.820	
1918	3.564	1.876	2.143	2.740	1.331	4.588	5.197	
1919	3.282	2.213	1.925	2.298	1.453	4.094	5.217	
1920	3.196	2.540	2.080	2.089	1.362	3.838	5.099	
1921	2.848	2.420	2.289	2.033	1.494	3.498	4.889	
1922	3.182	2.842	2.479	2.116	1.471	3.654	5.088	

1923	3.332	2.955	2.046	2.221	1.454	3.750	5.661
1924	3.330	3.290	2.379	2.223	1.475	3.877	5.724
1925	3.619	3.280	2.627	2.348	1.514	4.054	5.770
1926	3.760	3.345	2.680	2.353	1.504	3.889	6.064
1927	4.063	3.270	2.931	2.281	1.502	4.188	6.040
1928	4.338	3.488	3.040	2.424	1.604	4.221	6.033
1929	4.246	3.708	3.013	2.487	1.509	4.336	6.336
1930	4.025	3.567	2.955	2.345	1.499	4.287	5.667
1931	3.344	3.334	2.717	2.313	1.600	4.049	5.155
1932	3.055	3.117	2.500	2.371	1.731	4.057	4.436
1933	2.802	3.337	2.644	2.338	1.709	4.158	4.319
1934	3.063	3.300	2.870	2.329	1.732	4.418	4.629
1935	3.278	3.216	3.062	2.533	1.827	4.569	4.965
1936	3.422	3.341	3.310	2.518	1.889	4.755	5.639
1937	3.709	3.532	3.643	2.671	1.984	4.899	5.880
1938	3.771	3.516	3.973	2.669	2.278	4.938	5.568
1939	3.959	3.773	4.248	2.835	2.328	4.934	5.961
1940	4.458	3.182	4.243	2.822	2.328	5.402	6.384
1941	4.973	2.605	4.486	2.763	2.308	5.895	7.437
1942	5.780	2.347	4.510	2.712	2.264	6.019	8.746
1943	5.968	2.251	4.629	2.446	2.267	6.102	10.198
1944	6.116	1.906	4.785	1.982	2.136	5.835	10.900
1945	5.862	2.026	3.492	1.547	1.081	5.560	10.581
1946	5.696	3.035	1.966	2.013	1.169	5.315	8.466
1947	5.824	3.257	2.248	2.351	1.248	5.204	8.066
1948	5.801	3.458	2.595	2.466	1.397	5.315	8.232
1949	5.807	3.894	2.964	2.629	1.457	5.481	8.097
1950	6.113	4.159	3.338	2.840	1.563	5.623	8.610
1951	6.278	4.379	3.652	3.034	1.732	5.812	9.326
1952	6.550	4.460	3.937	3.241	1.905	5.785	9.519
1953	6.672	4.552	4.223	3.454	2.017	6.039	9.737
1954	6.454	4.735	4.505	3.611	2.101	6.254	9.443
1955	6.878	4.968	5.002	3.799	2.276	6.447	9.802
1956	7.234	5.166	5.299	3.938	2.396	6.513	9.821
1957	7.249	5.422	5.533	4.136	2.548	6.605	9.809
1958	7.190	5.375	5.666	4.322	2.671	6.581	9.582
1959	7.296	5.602	6.017	4.554	2.888	6.807	9.974
1960	7.339	5.938	6.479	4.764	3.237	7.183	9.995
1961	7.422	6.199	6.691	5.132	3.594	7.363	10.101
1962	7.803	6.495	6.925	5.497	3.879	7.376	10.475
1963	8.057	6.727	7.048	5.848	4.165	7.615	10.768
1964	8.435	7.091	7.444	6.029	4.603	7.976	11.241
1965	8.833	7.363	7.765	6.119	4.818	8.127	11.758
1966	9.260	7.683	7.921	6.396	5.283	8.236	12.218
1967	9.361	7.979	7.894	6.807	5.814	8.380	12.360
1968	9.697	8.258	8.303	7.333	6.541	8.686	12.749
1969	10.084	8.766	8.837	7.703	7.206	8.831	12.987
1970	10.202	9.185	9.203	7.803	7.889	8.987	12.825
1971	10.656	9.534	9.369	7.890	8.122	9.117	13.074
1972	11.143	9.869	9.704	8.056	8.681	9.405	13.589
1973	11.866	10.323	10.110	8.573	9.287	10.058	14.103
1974	12.225	10.574	10.124	8.977	9.001	9.885	13.875
1975	12.358	10.498	10.000	8.688	9.088	9.808	13.599
1976	12.949	10.899	10.594	9.214	9.453	10.081	14.126
1977	13.251	11.200	10.929	9.485	9.857	10.322	14.606
1978	13.714	11.526	11.256	9.799	10.267	10.699	15.192
1979	14.110	11.848	11.716	10.355	10.709	10.986	15.322
1980	14.143	11.980	11.837	10.773	11.098	10.723	15.130
1981	14.484	12.054	11.835	10.860	11.441	10.581	15.310

1982	13.880	12.293	11.766	10.870	11.686	10.772	14.765
1983	14.206	12.322	11.984	10.956	11.972	11.147	15.194
1984	14.995	12.435	12.371	11.251	12.493	11.360	16.131
1985	15.588	12.617	12.641	11.520	13.003	11.747	16.581
1986	15.947	12.856	12.927	11.792	13.242	12.123	16.884
1987	16.484	13.049	13.145	12.121	13.733	12.659	17.339
1988	17.095	13.447	13.569	12.574	14.456	13.150	17.966
1989	17.596	13.769	13.989	12.951	15.101	13.460	18.357

Source: raw data from Maddison (1979, 1991) and Summers and Heston (Penn World Tables, Mark 6, NBER gopher). Computations by the author. See the main text for details.

Table XVII
GDP per head in nine industrialised countries (1870-1989)
(1985 US 1000 relative dollars)

	Australia	Austria	Belgium	Denmark	Finland	Netherlands	Norway	Sweden	Switzerland
1870	3.123	1.433	2.104	1.547	0.933	2.064	1.190	1.316	1.848
1871	2.903	1.523	2.093	1.540	0.922		1.201	1.332	
1872	3.128	1.521	2.203	1.613	0.937		1.269	1.381	
1873	3.365	1.472	2.200	1.589	0.976		1.287	1.492	
1874	3.115	1.524	2.255	1.619	0.985		1.318	1.533	
1875	3.538	1.518	2.232	1.631	0.991		1.343	1.452	
1876	3.410	1.539	2.243	1.646	1.030		1.363	1.531	
1877	3.437	1.578	2.250	1.581	0.991		1.351	1.464	
1878	3.650	1.616	2.295	1.624	0.959		1.292	1.439	
1879	3.470	1.591	2.298	1.660	0.955		1.292	1.400	
1880	3.529	1.600	2.391	1.686	0.945	2.306	1.320	1.461	
1881	3.636	1.651	2.395	1.687	0.908		1.328	1.465	
1882	3.285	1.647	2.447	1.731	0.984		1.324	1.523	
1883	3.637	1.700	2.453	1.777	1.006		1.320	1.533	
1884	3.532	1.730	2.447	1.766	0.998		1.339	1.563	
1885	3.638	1.705	2.448	1.757	1.007		1.345	1.544	
1886	3.563	1.745	2.460	1.805	1.044		1.343	1.526	
1887	3.825	1.850	2.535	1.850	1.044		1.350	1.524	
1888	3.741	1.831	2.533	1.846	1.065		1.405	1.559	
1889	3.951	1.798	2.636	1.854	1.085		1.448	1.634	
1890	3.723	1.880	2.674	1.949	1.130	2.569	1.477	1.651	2.339
1891	3.938	1.928	2.649	1.974	1.105		1.478	1.666	
1892	3.391	1.951	2.685	2.007	1.063		1.501	1.697	
1893	3.145	1.943	2.696	2.031	1.097		1.532	1.696	
1894	3.194	2.035	2.706	2.053	1.145		1.523	1.718	
1895	3.069	2.068	2.740	2.141	1.221		1.519	1.786	
1896	3.244	2.078	2.771	2.191	1.284		1.544	1.873	
1897	3.010	2.101	2.798	2.212	1.329		1.598	1.922	
1898	3.425	2.197	2.820	2.217	1.365		1.579	1.944	
1899	3.379	2.221	2.852	2.280	1.315		1.601	1.971	2.540
1900	3.532	2.217	2.911	2.331	1.365	2.842	1.610	2.026	2.591
1901	3.379	2.204	2.902	2.399	1.339	2.735	1.635	1.990	2.637
1902	3.365	2.266	2.917	2.427	1.302	2.828	1.654	1.975	2.678
1903	3.588	2.263	2.943	2.543	1.379	2.861	1.638	2.112	2.720
1904	3.780	2.274	2.981	2.569	1.416	2.793	1.630	2.120	2.761
1905	3.769	2.378	3.028	2.585	1.425	2.844	1.641	2.129	2.801
1906	3.967	2.444	3.056	2.628	1.468	2.939	1.693	2.251	2.840
1907	4.063	2.569	3.068	2.694	1.501	2.909	1.749	2.283	2.875
1908	4.131	2.554	3.068	2.744	1.496	2.867	1.793	2.258	2.913
1909	4.384	2.521	3.098	2.814	1.542	2.967	1.824	2.222	2.949
1910	4.586	2.532	3.171	2.863	1.560	2.964	1.875	2.358	2.985
1911	4.492	2.589	3.237	2.980	1.586	3.008	1.919	2.375	3.019
1912	4.440	2.697	3.282	2.946	1.655	3.131	1.988	2.424	3.053
1913	4.523	2.667	3.292	3.022	1.727	3.178	2.078	2.450	3.086
1914	4.080	2.214	3.062	3.176	1.637	3.061	2.103	2.411	3.063
1915	3.812	2.041	3.009	2.919	1.539	3.081	2.170	2.396	3.074
1916	4.093	2.023	3.183	3.007	1.549	3.105	2.192	2.348	3.092
1917	4.190	1.989	2.746	2.795	1.293	2.847	1.994	2.044	2.751
1918	4.143	1.966	2.234	2.672	1.128	2.631	1.900	2.004	2.747
1919	3.977	1.737	2.644	2.982	1.357	3.235	2.200	2.112	2.937
1920	4.147	1.856	3.091	3.084	1.510	3.312	2.310	2.217	3.121

1921	4.468	2.039	3.165	2.947	1.542	3.478	2.093	2.116	3.045
1922	4.409	2.214	3.443	3.210	1.684	3.610	2.314	2.299	3.339
1923	4.402	2.187	3.537	3.512	1.789	3.638	2.349	2.411	3.525
1924	4.639	2.434	3.618	3.488	1.820	3.843	2.324	2.477	3.645
1925	4.693	2.591	3.611	3.373	1.905	3.949	2.451	2.558	3.897
1926	4.542	2.626	3.702	3.542	1.957	4.205	2.491	2.693	4.069
1927	4.440	2.697	3.811	3.588	2.092	4.320	2.575	2.769	4.262
1928	4.289	2.814	3.978	3.686	2.215	4.490	2.650	2.893	4.464
1929	4.187	2.846	3.912	3.910	2.223	4.465	2.886	3.061	4.580
1930	3.937	2.759	3.853	4.114	2.181	4.337	3.086	3.115	4.518
1931	3.725	2.530	3.762	4.128	2.111	4.070	2.829	2.993	4.299
1932	3.835	2.262	3.566	3.982	2.086	3.952	2.999	2.901	4.130
1933	4.022	2.180	3.623	4.076	2.210	3.890	3.054	2.945	4.316
1934	4.145	2.194	3.579	4.161	2.445	3.772	3.134	3.158	4.306
1935	4.282	2.237	3.788	4.221	2.530	3.869	3.252	3.349	4.273
1936	4.453	2.304	3.803	4.295	2.682	4.074	3.433	3.533	4.274
1937	4.667	2.428	3.840	4.367	2.815	4.264	3.537	3.690	4.464
1938	4.659	2.739	3.740	4.439	2.937	4.121	3.605	3.739	4.622
1939	4.627	3.152	3.986	4.617	2.788	4.352	3.753	3.979	4.601
1940	4.880	3.047	3.531	3.941	2.635	3.792	3.398	3.843	4.627
1941	5.373	3.245	3.373	3.523	2.718	3.557	3.460	3.888	4.566
1942	5.940	3.065	3.093	3.566	2.722	3.224	3.304	4.098	4.418
1943	6.097	3.128	3.022	3.913	3.024	3.124	3.214	4.241	4.341
1944	5.827	3.195	3.183	4.270	3.014	2.079	3.018	4.339	4.404
1945	5.469	1.327	3.354	3.903	2.822	2.109	3.348	4.405	5.607
1946	5.220	1.505	3.540	4.450	3.013	3.498	3.664	4.828	5.917
1947	5.275	1.667	3.715	4.649	3.041	3.962	4.035	4.886	6.547
1948	5.515	2.127	3.888	4.752	3.237	4.309	4.307	4.979	6.594
1949	5.728	2.534	4.020	4.920	3.390	4.616	4.347	5.107	6.848
1950	5.900	2.852	4.228	5.224	3.480	4.706	4.541	5.332	6.556
1951	6.004	3.046	4.445	5.147	3.734	4.745	4.705	5.506	7.002
1952	5.915	3.047	4.387	5.202	3.817	4.781	4.825	5.544	6.974
1953	5.959	3.179	4.505	5.459	3.802	5.134	5.000	5.659	7.135
1954	6.185	3.502	4.665	5.605	4.089	5.417	5.197	5.858	7.450
1955	6.379	3.888	4.862	5.543	4.252	5.750	5.248	5.986	7.860
1956	6.449	4.144	4.971	5.618	4.340	5.882	5.473	6.177	8.256
1957	6.432	4.385	5.031	5.825	4.503	5.967	5.582	6.416	8.455
1958	6.373	4.532	4.994	5.952	4.487	5.872	5.482	6.409	8.155
1959	6.852	4.647	5.119	6.320	4.712	6.079	5.715	6.566	8.542
1960	7.017	5.016	5.381	6.653	5.097	6.504	5.991	6.874	9.010
1961	7.035	5.253	5.621	7.032	5.448	6.437	6.316	7.229	9.610
1962	7.140	5.348	5.880	7.371	5.573	6.781	6.442	7.595	9.818
1963	7.488	5.533	6.092	7.361	5.715	6.933	6.634	7.934	10.082
1964	7.862	5.830	6.457	7.981	5.981	7.407	6.916	8.610	10.438
1965	8.060	5.964	6.630	8.278	6.276	7.689	7.224	8.998	10.646
1966	8.225	6.255	6.796	8.434	6.401	7.797	7.439	9.172	10.793
1967	8.541	6.418	7.023	8.648	6.506	8.116	7.837	9.356	10.986
1968	8.921	6.682	7.294	8.940	6.624	8.548	7.943	9.761	11.237
1969	9.361	7.080	7.761	9.459	7.264	8.992	8.231	9.937	11.738
1970	9.693	7.543	8.232	9.575	7.837	9.388	8.339	10.491	12.227
1971	9.878	7.890	8.502	9.763	7.984	9.669	8.663	10.818	12.609
1972	10.163	8.326	8.917	10.220	8.549	9.889	9.040	10.764	12.890
1973	10.428	8.682	9.417	10.528	9.073	10.267	9.346	11.293	13.187
1974	10.464	9.013	9.773	10.382	9.297	10.590	9.773	11.620	13.355
1975	10.554	8.989	9.600	10.282	9.364	10.488	10.124	11.869	12.370
1976	10.716	9.405	10.118	10.920	9.360	10.937	10.762	11.953	12.395
1977	10.797	9.807	10.155	11.064	9.346	11.124	11.100	11.719	12.735
1978	11.008	9.865	10.424	11.192	9.520	11.328	11.559	11.890	12.768
1979	11.309	10.335	10.638	11.209	10.186	11.517	12.103	12.321	13.057

1980	11.500	10.641	11.085	11.496	10.696	11.524	12.556	12.577	13.727
1981	11.610	10.608	10.965	11.395	10.819	11.366	12.639	12.567	13.848
1982	11.441	10.712	11.129	11.748	11.144	11.154	12.635	12.698	13.613
1983	11.514	10.977	11.172	12.054	11.407	11.269	13.162	12.919	13.647
1984	11.998	11.116	11.414	12.588	11.694	11.578	13.896	13.423	13.835
1985	12.411	11.386	11.507	13.123	12.034	11.827	14.583	13.701	14.339
1986	12.638	11.500	11.688	13.507	12.246	11.999	15.135	13.979	14.667
1987	12.900	11.711	11.897	13.395	12.696	12.048	15.577	14.339	14.869
1988	13.180	12.162	12.366	13.333	13.306	12.298	15.665	14.609	15.292
1989	13.587	12.585	12.876	13.512	13.934	12.738	16.503	14.809	15.577

Source: raw data from Maddison (1979, 1991) and Summers and Heston (Penn World Tables, Mark 6, NBER gopher). Computations by the author. See the main text for details.

Figure 1

Difference between Canadian and US GDP per head

Figure 2

Difference between British and US GDP per head

Figure 3
Difference between German and US GDP per head

Figure 4
Difference between French and US GDP per head

Figure 5
Difference between Italian and US GDP per head

Figure 6
Difference between Japanese and US GDP per head

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