Convergence of GDP per capita in advanced countries over the twentieth century

Antonin Bergeaud, Gilbert Cette, Rémy Lecat

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Abstract

This study compares GDP per capita levels and growth rates across 17 advanced economies over the period 1890–2013 using an accounting breakdown and runs Phillips and Sul (Econometrica 75(6):1771–1855, 2007) convergence tests. An overall convergence process has been at work among advanced economies, mainly after WWII, driven mostly by capital intensity and then TFP, while trends in hours worked and employment rates are disparate. However, this convergence process came to a halt during technology shocks, during the two world wars and since the 1990s, with the convergence of advanced economies stopping far from the level of US GDP per capita.

1 Introduction

The abundant literature devoted to comparisons of GDP per capita across countries has mainly focused on two related questions: (i) is there a convergence of GDP per

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capita across countries and (ii) what factors better explain growth in GDP per capita? Many answers have been put forward (see Islam 2003 for a summary). The most general view is that economic development relies on the social capability of a country making it cost effective to adopt the leaders technology (Abramovitz and David 1996; Temple and Johnson 1998). Social capability is a generic term embracing the quality of production factors and the ability to adopt new technologies and assigns a particularly important role to the quality of institutions and to the general level of education (see for example Barro 1991; Barro and Sala-i-Martin 1997; Hall and Jones 1999, and, for more recent assessment, Aghion and Howitt 2008; Madsen 2010b, a or Barro 2015). Among the most important institutional factors, it is worth mentioning property rights, labour and product market regulations, financial system development and regulations, the quality of the legal system and even democracy, as shown by Acemoglu et al. (2019). Technical progress and innovation crucially depend on these institutional and educational factors (see for example Aghion and Howitt 1998, 2006, 2008) whose role could have increased over the last decades, as suggested by Crafts and O'Rourke (2014). Observed differences in GDP levels and advanced economies failure to catch up with the USA could thus result from a failure to adopt the leading practices for these factors. But cultural explanations can also be put forward, for example the leisure–work trade-off that results in significant differences in working time (even though this trade-off could be the result of different tax incentives, see Prescott 2004, for a Europe–United States comparison). In this study, we propose taking a new look at these two questions, drawing on a unique long database, and we present a comparison of GDP per capita, both in terms of levels and growth rates, and break it down into its main factors across the main advanced economies for over a century. More specifically, we break GDP per capita down into four components: total factor productivity (TFP), capital intensity, working time and employment rate and quantify the contributions of these components to the differences in GDP per capita across countries since 1890. To do so, we rely on a methodology developed by Phillips and Sul (2007, 2009) to test the convergence hypothesis in terms of GDP per capita and its components over different sub-periods. The analysis is carried out over the period 1890–2013 using annual data and, from 1974, using quarterly data, and is the first to present a formal convergence test on GDP per capita and its main components over such a long period and across a relatively large set of countries, with data converted in purchasing power parity and on the basis of, insofar as possible, consistent assumptions. This enables us to consider the role of each contributor of GDP per capita in explaining the existence (or not) of convergence dynamism over the entire twentieth century. This study yields the following results regarding the convergence process over the twentieth century: (i) an overall convergence process is at work among advanced economies, mainly after WWII, first driven by capital intensity and then by TFP, while trends in hours worked and, even more so, employment rates are more disparate; (ii) however, this convergence process is not continuous;[1] (iii) employment rates and hours worked have

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[1] For example, it has been particularly hampered since 1990. Indeed, the convergence of the euro area, the United Kingdom and Japan towards the level of US GDP per capita has stopped far from the US level, while reforming or structurally flexible countries have accelerated thanks to the information and communications technology shock. This fact has already been identified in the literature (see for example Crafts and ORourke 2013) and means that the GDP per capita catch-up process is not always continuous.

not contributed to the overall convergence process, with club convergence very often appearing for these variables among European countries on the one hand and Anglo-Saxon countries on the other. Dynamics have been especially divergent between these two groups since 1974, as opposite labour policies have been implemented. Section 2 presents the data set. Section 3 presents Phillips and Sul (2007)'s convergence tests on GDP per capita and its components over different sub-periods. Section 4 presents robustness tests, and Sect. 5 concludes.

2 Background

2.1 The data

In order to build series for GDP per capita and to break it down, we needed few series but over a long period for the 17 advanced economies under review. These 17 countries correspond to the G7 countries (the USA, Japan, Germany, France, the United Kingdom, Italy and Canada), the other three largest countries of the euro area (Spain, the Netherlands and Belgium), two other euro area countries (Portugal and Finland) and five other OECD countries that are relevant for productivity analysis because of their specificities: a high-productivity level at the beginning of the period for Australia, a particular industrial structure associated with very high standards of living for Norway and Switzerland and important structural policy changes for Sweden and Denmark. From these countries, we have reconstituted a euro area by summing figures for Germany, France, Italy, Spain, the Netherlands, Belgium, Portugal and Finland, these 8 countries representing more than 90% of the total euro area GDP in 2010 and a very large share in the past. The analysis is carried out over the period 1890–2013 using annual data and from 1974 using quarterly data in order to gain statistical power. The starting database was the one built by Cette et al. (2009) covering the USA, Japan, France and the United Kingdom for the period 1890–2006. Bergeaud et al. (2016) then considerably enlarged this database to include 13 countries. For this study, we added four countries to the data set (Belgium, Denmark, Portugal and Switzerland) and updated the series up to 2013, taking into account the latest changes in national accounting methodologies.[2]

To compute GDP per capita indexes over this long period (1890–2013), we rely on Maddison (2001) whose series were updated by Bolt and Zanden (2014). Maddison provides data for GDP (Y) and population (P), on a yearly basis, with series that most of the time start from 1820. We supplement these data with national accounts. For other series and in particular to compute the TFP index used in the accounting breakdown of GDP per capita, three basic series are needed for each country: employment (N), hours worked (H) and physical capital stock (K). The capital indicator is constructed using the perpetual inventory method applied to each of the two components (equipment KE and buildings KB) from the corresponding investment data (IE and IB). We assume a geometric depreciation of the capital stock with yearly depreciation rates of

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[2] See "Online Appendix B" for further details about data construction, updates and sources. See also the dedicated website of this database: www.longtermproductivity.com to download the series.

10% for equipment and 2.5% for buildings following Cette et al. (2009), which are considered constant across time and space. The damages caused by WWI and WWII, the earthquakes in Japan and the civil war in Spain are, insofar as possible, taken into account to build the capital series. Finally, GDP and capital stock series are given in 2010 constant national currencies and converted into US dollars at purchasing power parity (ppp) with a conversion rate from the Penn World Tables. The series are converted to draw comparisons of levels across countries and have a significant effect on relative levels. In particular, the choice of the base year for the ppp conversion is not neutral and reflects a GDP structure at a specific date in time (see Bergeaud et al. 2016 for a more detailed discussion).

For such long and aggregate historical data series, we rely on country-specific studies by economists and historians. It should however be noted that many of these data are subject to uncertainty and inaccuracy and strong assumptions are required to reconstitute some countries.[3] We may nevertheless consider that the orders of magnitude of these estimates and the ensuing large differentials in GDP per capita and productivity levels and growth rates are fairly reliable and meaningful.

Decomposition

GDP per capita is the ratio of GDP over population (Y/P).[4] The employment rate is the ratio of employment over population (N/P). We consider two productivity indexes: labour productivity (LP) and TFP. The LP indicator is the ratio of GDP (Y) to labour (L): $LP = Y/L$. Labour is considered to be the number of hours worked, which means here that it is the product of total employment (N) by the average working time per worker (H): $L = NH$. Labour is considered homogeneous.

LP is itself broken down into two sub-components, following Solows "growth accounting approach" (Solow 1956, 1957): TFP and the capital to labour ratio (K/L) powered by the elasticity of GDP to capital (α). The capital to labour ratio is known as capital intensity, and its growth corresponds to the capital deepening mechanism. The TFP indicator is the ratio of GDP (Y) to an aggregation function $F(.)$ of the two production factors considered, capital (K) and labour (L): $TFP = Y/F(K, L)$. Here, capital is the sum of two components, equipment (KE) and buildings (KB): $K = KE + KB$. Assuming a Cobb–Douglas production function, TFP corresponds to the usual relation: $TFP = Y/(K^{\alpha} L^{\kappa})$, where α and κ are the elasticities of output with respect to inputs K and L. Assuming unitary returns to scale ($\alpha + \kappa = 1$), the relation becomes: $TFP = Y/(K^{\alpha} L^{1-\alpha})$. We take as the measure of capital (K) in use in period t the volume of the stock of capital set-up at the end of period $t - 1$. The TFP term stands for the impact on growth of autonomous technical progress and of other unmeasured factors and is a residual, while the other components of the equation are individually computed. It is important to note that the improvement in the quality of labour through education, better health, etc. is included in this TFP term, as our labour input only reflects the number of hours worked. More generally, the role played by

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[3] For example, backdating consistent economic series at unchanging border is almost impossible in the case of countries such as Germany whose territories changed considerably over the period 1890–2013.

[4] The accounting breakdown for GDP per capita is described in "Online Appendix A"

technical progress through TFP in the convergence process may be overestimated due to unmeasured inputs (education, intangibles), input quality and economies of scale.[5] In order to compute the TFP index, it is also necessary to measure the output elasticities with respect to the different inputs. In addition to the hypothesis of constant returns to scale ($\alpha + \kappa = 1$), it is generally assumed that production factors are remunerated at their marginal productivity (at least over the medium to long term, which is the horizon of the study), which means that it is possible to estimate factor elasticities on the basis of the share of their remuneration (cost) in total income (or total cost). Given that labour costs (wages and related taxes and social security contributions) represent roughly two thirds of income, it is simply assumed here that $\alpha = 0.3$. Here again, it appears that the results of the study are robust to this calibration of α and remain roughly stable for other realistic values.

2.2 Convergence

With this new data set, we are able to study the convergence process over a very long-time period and for various economic quantities, and in particular GDP per capita and TFP.[6]

According to Galor (1996), three different hypotheses for convergence are put forward. First, the absolute convergence hypothesis suggests that GDP per capita converges to a common steady-state equilibrium over the long run, no matter what their initial structural characteristics or initial levels of GDP per capita were. Second, the conditional convergence hypothesis also assumes that this convergence to a common steady state occurs independently of initial levels, but only among countries that share common structural characteristics (demography, policy, geography, etc. see Barro 2015, for recent estimates). Finally, the club convergence hypothesis describes a situation in which groups of countries with similar initial conditions and identical in terms of structural characteristics converge to a common steady-state equilibrium. In this latter case, multiple equilibria exist and countries can reach one of them if their initial levels belong to the same "basin of attraction" of a steady state (see Durlauf and Johnson 1995; Galor 1996 and Islam 2003, for more details). Convergence can also be expressed by two different concepts, β- or σ-convergence, which can be combined with the absolute, conditional or club convergence hypothesis. β-convergence entails that the lower the level of the initial indicator, the faster its growth; σ-convergence entails that dispersion within the sample decreases with time. How to test for convergence has been a widely discussed topic since the seminal work of Barro and Sala-i-Martin (1991, 1995, 1997). The club convergence hypothesis was first tested in the β-convergence framework (see Durlauf and Johnson 1995, for an example and Bartkowska and Riedl 2012, for a review).

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[5] In another paper (Bergeaud et al. 2018), the author measures that human capital accounts for 20% to 33% of the growth rate of the Solow residual that we call TFP in the present study.

[6] This offers two advantages over existing databases. First compared to the Maddison (2001) database, we provide estimates of TFP, capital intensity and labour in addition to his GDP per capita estimates. Second, compared to the Penn World Tables, we cover a longer time period and our capital stock estimates are less affected by the initial year steady-state assumption.

This approach has its limitation since it requires identifying a priori the factors that can explain the existence of multiple equilibria and preselecting groups of countries according to these criteria. In order to avoid making such arbitrary choices, more recent methods have been developed to endogenise the groups of countries. Among them, Phillips and Sul (2007) built a methodology that relates to the family of σ-convergence tests. Their methodology offers many advantages in addition to being a "simple regression based convergence test". First, it is used to analyse co-movements and convergence even in the case of cross-sectional heterogeneity when co-integration tests are no longer useful. Second, it distinguishes between global convergence, divergence or club convergence across different economies. Club convergence in this methodology consists in statistically determining empirical clusters. To be fully consistent with the club convergence hypothesis described by Galor (1996), one should then test for common structural characteristics justifying convergence to a similar club. In a subsequent paper, Phillips and Sul (2009) present various applications of their test. One of them consists in applying their methodology to per capita income for a large set of advanced and emerging economies over the 1960–2001 period and for a set of advanced economies in the twentieth century. They find significant convergence for advanced economies and subgroup convergence among the largest sample. Our analysis however differs in some aspects. First, our data set enables us to study the convergence of many more economic indicators, and namely TFP. Second, our variables allow us to achieve a breakdown of GDP per capita, which sheds new light on what is the driver of the overall convergence. And third, we study the convergence dynamism over different sub-periods. This point, we believe, is important because our data set only includes so-called advanced economies which have been selected because they all have relatively high income per capita and for which global convergence is clearly not a surprise.[7] However, perhaps more interestingly, we will see that convergence is not a smooth and automatic process. For example, the convergence process towards the level of US GDP per capita has stopped over the last few decades in the euro area, but also in some specific countries which are still far from the US level.

3 Convergence test: methodology and results

A first hint at the convergence process is provided by the coefficients of variation (see Fig. 1), which standardise the standard deviations of a random variable by its mean.[8] For GDP per capita, the coefficient of variation decreased slowly from 1890 to WWII, increased sharply during WWII and decreased markedly until the 1990s. It has been stable since. This reflects an overall σ-convergence over the entire period, brutally

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[7] The use of different sub-periods should be understood as follows: given the set of information contained in the time series during a given sub-period, does the panel of countries tend to converge towards a common steady state at some point in the future (even if this future is long after the end of this sub-period)? Hence, if the test suggests convergence during one sub-period, this does not mean that the convergence process will occur during this sub-period, but rather that the countries display convergence dynamics during this sub-period.

[8] To control for outliers and check for consistency, a similar chart is presented in "Online Appendix C, section C.3". This additional chart shows the normalised interquartile range for each series (see "Online Appendix" for details).
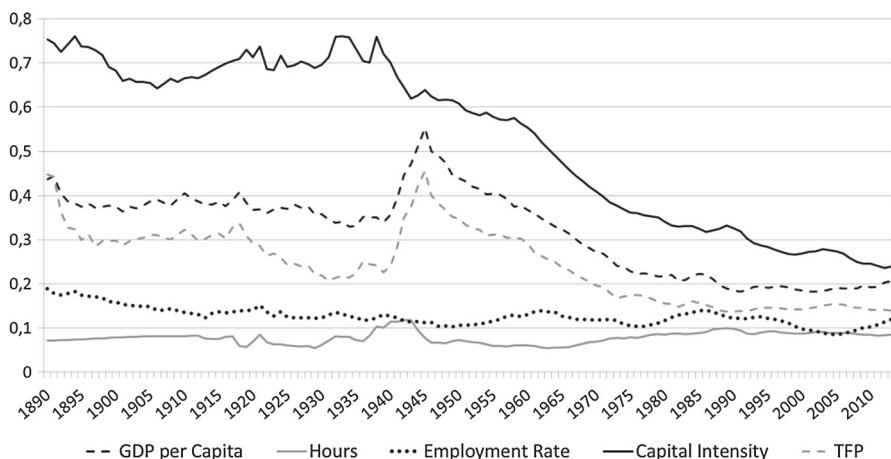
Fig. 1 Coefficients of variation (standard deviation/mean) for GDP per capita, hours worked, employment rate, capital intensity and TFP, calculated each year for the sample of 17 countries and over the period 1890–2013

reversed during WWII and halted since the 1990s.[9] This overall convergence is driven by capital intensity,[10] whose coefficient of variation has declined sharply since the end of the 1930s, and by TFP, whose coefficient of variation follows the same path as that of GDP per capita. By contrast, the coefficients of variation for hours worked and the employment rate are almost flat (slightly decreasing for the employment rate), which suggests an absence of convergence for both indicators, but from a much lower dispersion level, which may be due to the fact that both indicators are bounded. We need to complement this first hint by looking at more formal tests, which we describe in Sect. 3.1, before presenting their results in Sect. 3.2 and various robustness tests and discussions in Sect. 4.

3.1 The "log-t" test of convergence

The five coefficients of variation presented in Chart 4 point to convergence dynamics for at least GDP per capita, capital intensity and TFP over the entire period. However, during some sub-periods, for example before 1950, this convergence process is less obvious. Does this trend result from the fact that no convergence behaviour is observed during this period or does it reflect the fact that countries cluster in different groups approaching a common steady state? This question requires looking deeper into the convergence process, and to do so, we rely on a methodology developed by Phillips and Sul (2007), which is related to the family of σ-convergence tests. Phillips and Sul (2007) constructed a "log-t" test of convergence based on a single regression. This test has the advantage of allowing for heterogeneity in the speed of convergence. We

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[9] In fact, it can be demonstrated that σ-convergence implies β-convergence (see Young et al. 2008).

[10] Whose dynamics could in turn be driven by the convergence in the cost of capital across advanced economies, see Mazet-Sonilhac and Mésonnier (2016).

used this test and the algorithm described in Phillips and Sul (2009) to identify club convergence clusters for different time series and different sub-periods.

Formally, the main idea of the test is to write the log of our variable of interest, denoted $x_{i,t}$, (x standing for GDP per capita, productivity, capital intensity... i indexes the country and t the year) as the product of a time-varying idiosyncratic term $\delta_{i,t}$ and a common trend μ_t so that:

$$log(x_{i,t}) = \delta_{i,t}\mu_t$$

As opposed to a more classical representation of panel data: $log(x_{i,t}) = a_{i,t} + g_{i,t}$ where g is a permanent component and a a transitory one, the breakdown presented above enables us to distinguish between pure idiosyncratic effects and a common trend. Here, $\delta_{i,t}$, which stands for the country-specific effect, can also be seen as the distance between country i indicator level at time t and the common trend μ_t or equivalently, the part of the common trend that is included in country i variation at time t. Unfortunately, it is in general impossible to estimate $\delta_{i,t}$ directly. For this reason, Phillips and Sul (2007) introduce the relative transition coefficient $h_{i,t}$ constructed as the ratio of $log(x_{i,t})$ on the cross-sectional mean of $log(x_{i,t})$:

$$h_{i,t} = \frac{log(x_{i,t})}{\frac{1}{N}\sum_{j=1}^{N}log(x_{j,t})} = \frac{\delta_{i,t}}{\frac{1}{N}\sum_{j=1}^{N}\delta_{j,t}} \tag{1}$$

The relative transition coefficient $h_{i,t}$ measures the divergent behaviour of country i and its distance to a common steady state. When all countries converge, then $\forall i \in \{1, 2 \dots N\}, h_{i,t} \underset{t\to+\infty}{\longrightarrow} 1$ and the modified cross-sectional variance of h:

$$H_t = \frac{1}{N}\sum_{i=1}^{N}(h_{i,t} - 1)^2 \underset{t\to+\infty}{\longrightarrow} 0 \tag{2}$$

With these results in mind, it is possible to derive a test of convergence. To do so, Phillips and Sul (2007) assume that: $\delta_{i,t} = \delta_i + \frac{\sigma_i\xi_{i,t}}{t^k \log(t)}$ for all i, where δ_i is fixed, $\xi_{i,t}$ is $iid(0, 1)$ and σ_i is a positive parameter.[11]

This formulation shows that $\delta_{i,t}$ converges towards a common δ_i as long as $k \geq 0$. The null hypothesis of convergence is therefore: $H_0 : \delta_i = \delta$ for all i and $k \geq 0$, against the alternative hypothesis: $H_A : \delta_i \neq \delta$ for some i or $k < 0$.

Thus, the test of convergence can be boiled down to a test on the sign of k. Phillips and Sul (2007) then show that this test is a Student test on the sign of the estimate of coefficient β in the following equation:

$$log\left(\frac{H_1}{H_t}\right) - 2\log(log(t)) = a + \beta log(t) + \varepsilon_t, \quad \text{for } t > rT. \tag{3}$$

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[11] To be more accurate, the real assumption is that $\delta_{i,t} = \delta_i + \frac{\sigma_i\xi_{i,t}}{t^k L(t)}$ where L is a slowly varying function satisfying: $L(at)/L(t) \longrightarrow 1$ as $t \longrightarrow \infty$ for all $a > 0$ and $L(t) \longrightarrow \infty$. The logarithm is a good candidate, and it is the function which is recommended by Phillips and Sul (2007) based on Monte Carlo simulations.

In this equation, r is a coefficient whose purpose is to ensure that the first part of the time series is not taken into account in the regression. This condition is dictated by the statistical need to focus on the asymptotic representation of the transition distance H_t (see Phillips and Sul 2007 for more details). The 2log $(log(t))$ acts as a commuting term: in the case of convergence, H_t is asymptotically equal to 0 so that $\log\left(\frac{H_1}{H_t}\right)$ becomes very large. However, in the case of divergence, H_t can take any finite value and the 2log (log (t)) ensures that the left-hand side variable tends towards minus infinity. Finally, β is our coefficient of interest. Under the null hypothesis of convergence, $\beta \xrightarrow{p} 2k$ where k has been defined above. We can then use a one-sided t test robust to heteroskedasticity and autocorrelation (HAC), and we can reject H_0 if the test statistic is lower than -1.65. Following the recommendations of Phillips and Sul (2007) based on Monte Carlo simulations, we set the coefficient r to 0.2. The regressions are based on an OLS estimation with Newey–West standard errors. Based on this test, it is possible to know whether there is any evidence of convergence in the sample, i.e. whether H_0 cannot be rejected. In that case, the value of β also provides insight into the speed of convergence.[12] However, if the null hypothesis is rejected, i.e. if there is neither absolute nor conditional convergence, it is still possible to look at club convergence. Phillips and Sul (2007) have constructed an algorithm to detect clusters of countries that gather into clubs, the description of which is given in "Online Appendix C". In the next section, we run this algorithm to: (i) detect any evidence of convergence according to the "log-t" test (if the null hypothesis is not rejected) and (ii) look at clubs of convergence if the null hypothesis is rejected.

3.2 Results

The convergence and club convergence detection test described in the previous section has been carried out on our series of GDP per capita. In addition, we run the same test for the four contributors discussed in this paper: capital intensity, employment rate, hours worked and TFP. It is then possible to see whether countries are converging in terms of GDP per capita, or to which convergence club they belong, and which contributor is the most responsible for this. In addition, although it does not take part in the breakdown, we also run the test for LP. The results are presented in Table 1 and confirm the intuition drawn from the evolution of the coefficients of variation in Fig. 1. Over the entire period, GDP per capita converges at a moderate pace,[13] which confirms the convergence test results of Phillips and Sul (2009) regarding OECD countries' per capita income over the period 1870–2001. This convergence is driven by TFP, which converges in level ($\beta > 2$) and particularly rapidly for capital intensity. (The same conclusion can be drawn when looking at LP.) A certain degree of convergence takes place within different clubs for hours worked and employment rates, but there are four

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[12] In particular, if β is larger than 2 and if the common trend μ_t follows a random walk with drift, then Phillips and Sul (2007) argue that there is evidence of convergence in level, whereas if β is between 0 and 2, there is only evidence of convergence in growth rate. Consistently with the study of the trend in GDP per capita presented in Phillips and Sul (2009), we consider that this is the case for our series.

[13] Barro (2015) finds conditional β-convergence in GDP per capita since 1870 over 28 countries at a 2.6% annual convergence rate.

Table 1 Results when the Phillips–Sul club convergence test is used on the set of 17 countries in different sub-periods and for six different variables on yearly data

Period	GDP per capita	Labour productivity	Capital intensity	Employment rate	Average hours worked	TFP
1895–2013	(1.2)	(3.1)	(2.8)	**Gr1:** AU, CA, CH, DE, DK, FI, FR, GB, JP, NL, NO, PT, SE, US (0.17) **Gr2:** BE, ES, IT (1.40)	**Gr1:** AU, CA, ES, FI, IT, JP, PT, US (0.56) **Gr2:** CH, SE (−0.04)* **Gr3:** BE, DE, GB, NL (0.11) **Gr4:** DK, FR (−0.39)* **NOCV:** NO	(2.0)
1895–1950	**Gr1:** AU, CA, CH, NO, SE, US (0.32) **Gr2:** DK, FI, GB (0.25) **Gr3:** BE, FR (−0.18)* **Gr4:** DE, NL (−0.50)* **Gr5:** ES, IT, JP, PT (0.31)	**Gr1:** AU, CA, US (0.56) **Gr2:** GB, SE (1.52) **Gr3:** FI, FR (−1.0)* **Gr4:** DE, NL (−1.1)* **Gr5:** ES, IT, JP, PT (−0.14) **NOCV:** BE, CH, DK, NO	(0.38)	**Gr1:** CH, DE, DK, FI, FR, GB, IT, JP, NO, SE (0.80) **Gr2:** BE, CA, NL, US (0.66) **NOCV:** AU, ES, PT	**Gr1:** AU, DE, ES, IT, JP, NL, PT (0.44) **Gr2:** BE, CA, DK, FI (0.20) **Gr3:** GB, US (−0.1)* **Gr4:** FR, NO, SE (−0.22)*	(0.098)*
1950–2013	(0.40)	(0.80)	(1.1)	**Gr1:** AU, CA, CH, DE, DK, JP, NL, NO, PT, SE, US (0.31) **Gr2:** BE, ES, FI, FR, GB, IT (0.27)	**Gr1:** AU, CA, ES, FI, IT, JP, PT, SE, US (0.73) **Gr2:** BE, FR (0.53)* **Gr3:** DE, DK, NL (0.91) **NOCV:** CH, GB, NO	(0.66)

When no country is indicated, this means that there is global convergence. (The null hypothesis of convergence of the "log-t" test cannot be rejected.) The figure in brackets is the estimated value of β (see previous section on the "log-t" test methodology for details) either for the group or for the whole set of countries in case of global convergence. The larger the β coefficient, the faster the speed of convergence. When a star is added to the coefficient, e.g. (0.0002)*, this means that the associated t-stat is larger than −1.65 but below 1.65, so the coefficient cannot be interpreted as the speed of convergence. (The convergence is defined as "weak" in Phillips and Sul 2007.) NOCV indicates that the following countries do not converge and do not belong to any club. A β coefficient of the log test higher than 2 suggests convergence in level (see Phillips and Sul 2009). List of countries: Australia (AU), Belgium (BE), Canada (CA), Switzerland (CH), Germany (DE), Denmark (DK), Spain (ES), Finland (FI), France (FR), the United Kingdom (GB), Italy (IT), Japan (JP), the Netherlands (NL), Norway (NO), Portugal (PT), Sweden (SE) and the United States of America (USA)

clubs for hours worked and two for employment rates, and the pace of convergence is slow within these clubs.

We now look at whether the dynamics of our series when restricted to different sub-periods are such that we can predict convergence in the future.

– From 1895 to 1950 (Table 1), convergence in GDP per capita is rejected and only occurs within disparate clubs and at a very slow pace. This reflects the impact of WWII which led to a major reversal in the convergence process. This reversal hinges both on the US single "One big wave" (Gordon 1999) and on the disruptions caused by WWII. Indeed, if one looks at club 1 for both GDP per capita and LP, we can see that this group of leaders only contains countries that did not experience the war on their territory. At a very slow pace, an overall convergence is detected for TFP and capital intensity, but none for hours worked and employment rates, for which many convergence clubs appear with a few countries belonging to none of these clubs.

– From 1950 to 2013 (Table 1), an overall convergence in GDP per capita is detected, at a moderate pace and driven mostly by capital intensity and then TFP. Convergence within several clubs is detected for employment rates and hours worked, but at a slow pace. For employment rates, two clubs appear, with several European countries (Belgium, Spain, Finland, France, the United Kingdom and Italy) on the one side and the rest of the sample on the other. The first group displays a decrease in the employment rate until the mid-1980s (1990s for France) and then an increase until the Great Recession. The second group shows the reverse and is characterised by a higher rate of employment. Three groups appear for hours worked, with no convergence detected for Switzerland, the United Kingdom and Norway, which emphasises the scattered trend of hours worked over the period.

– Over the 1974–1990 period (Table 2), two GDP per capita convergence clubs stand out, with most European countries on the one side (characterised by an average level of GDP per capita and slowing growth) and other countries on the other. Spain and Portugal, with their low level of GDP per capita and fast growth, do not converge within any club. Over the period, no overall convergence is detected, while clubs and singletons are detected for other indicators. Two clubs emerge for capital intensity, while the United Kingdom, Norway and Portugal diverge. Three clubs are detected for TFP, pointing to divergent responses of advanced countries to the oil shocks over the period (both policy reaction to inflation and structural adaptation to the higher cost of energy). Trends in employment rates and hours worked are particularly scattered, with four clubs and several singletons. The two GDP per capita clubs cannot be attributed to one specific indicator as the two clubs do not appear in any of the clubs for the other indicators.

– Over the 1990–2013 period (Table 2), trends are particularly scattered with three clubs displaying a slow pace of convergence and Portugal diverging. No overall convergence appears for any other indicators, with two or three clubs of slow convergence and Norway diverging for labour productivity, capital intensity and the employment rate. Indeed, the decade-long convergence process with the USA came to a halt in many countries, despite GDP per capita level still far from the USA (at about 80% of the USA for the euro area, the UK and Japan), for different

Table 2 Results when the Phillips–Sul club convergence test is used on the set of 17 countries in different sub-periods and for six different variables on quarterly data

Period	GDP per capita	Labour productivity	Capital intensity	Employment rate	Average hours worked	TFP
1974–2013	(0.10)	(0.15)	(0.29)	(0.041)*	**Gr1:** AU, BE, CA, CH, DK, ES, FI, GB, IT, JP, PT, SE, US (0.24) **Gr2:** DE, FR, NL, NO (0.18)	(0.26)
1974–1990	**Gr1:** CH, FI, JP, NO, US (0.038)* **Gr2:** AU, BE, CA, DE, DK, FR, GB, IT, NL, SE (0.13) **NOCV:** ES, PT	**Gr1:** BE, CH, DK, ES, FR, NL (0.53) **Gr2:** AU, CA, DE, FI, GB, IT, JP, SE, US (0.27) **NOCV:** NO, PT	**Gr1:** BE, CH, DE, DK, ES, FR, JP, NL, SE, US (0.11) **Gr2:** AU, CA, FI, IT (0.40) **NOCV:** GB, NO, PT	**Gr1:** CA, CH, DK, JP, NO, SE (0.033)* **Gr2:** DE, FI, US (0.089)* **Gr3:** AU, GB, NL, PT (0.84) **Gr4:** BE, FR, IT (0.10)* **NOCV:** ES	**Gr1:** IT, PT, US (0.27) **Gr2:**AU, CA, ES, FI, GB (1.1) **Gr3:** BE, CH, FR, SE (0.60) **Gr4:** DE, DK, NL(0.27) **NOCV:** JP, NO	**Gr1:** BE, CA, CH, ES, FI, FR, JP, NL, NO (0.27) **Gr2:** AU, DE, DK, GB, IT, US (0.83) **Gr3:**PT, SE (-0.13)*
1990–2013	**Gr1:** AU, BE, CA, CH, DE, FI, GB, NL, NO, SE, US (0.046) **Gr2:** DK, ES, FR (0.098)* **Gr3:**IT, JP (-1.3)* **NOCV:** PT	**Gr1:** AU, BE, DE, DK, FI, FR, GB, NL, SE, US (0.33) **Gr2:** CA, CH, ES, IT, JP, PT (-0.021)* **NOCV:** NO	**Gr1:** AU, BE, FR, JP, NL, PT, US (0.14) **Gr2:** DE, DK, ES, SE (0.39)* **Gr3:** CA, CH, FI, GB, IT (0.39) **NOCV:** NO	**Gr1:** CA, CH (-0.006)* **Gr2:** AU, DE, DK, ES, FI, GB, JP, NL, PT, SE, US (0.27) **Gr3:** BE, FR, IT (1.3) **NOCV:** NO	**Gr1:** IT, US (0.40)* **Gr2:** AU, BE, CA, CH, DK, ES, FI, GB, JP, PT, SE (0.088) **Gr3:** DE, FR, NL, NO (-0.030)*	**Gr1:** AU, BE, CH, DE, DK, FI, FR, GB, NL, NO, SE, US (0.39) **Gr2:** CA, ES, IT, JP, PT (0.006)*

See Table 1

reasons: in continental Europe this was due to the limited diffusion of ICT relative to the United States, in Japan to the banking crisis and subsequent deflation, and in both to heavy labour and product market regulations. Conversely, the convergence process accelerated in some countries thanks to the structural reforms implemented in the aftermath of a crisis: Australia, Canada, Finland and Sweden. Finally, the Great Recession did not hit euro area countries and the rest of the world in the same manner: the shock was less brutal but more protracted in the euro area. These groups appear in different clubs: reforming countries all belong to the first GDP per capita convergence club, while less dynamic countries or countries in crisis are in the other groups or are diverging. For TFP, the clubs split into two: on the one side the countries with the weakest TFP growth (Canada, Spain, Italy, Japan, Portugal) and the other the remaining countries. Trends are more scattered for the other indicators.

– As regards the 1974–2013 period (Table 2), the overall global convergence detected for almost every series seems to mask a more complex transitional behaviour. Indeed, when the time period is split into two sub-periods (1974–1990 and 1990–2013), some convergence clubs emerge, whereas a few countries (namely Portugal and Norway) diverge.

If one looks more closely at TFP data, it appears that the global convergence is in fact the result of a merging between groups 1, 2 and 3 of the 1974–1990 period into one group that emerges in the next period (1990–2013). During this process, some countries were left behind and clustered into a second club. Over the 1990–2013 period, these countries, i.e. Italy, Japan and Spain,[14] joined the convergence path of Portugal, which had been a diverging country before 1990. Thus, even if the "log-t" test detects a global convergence for the whole 1974–2013 time period, this may in fact be the consequence of Italy, Japan and Spain slowly leaving the convergence path of other countries, leading to a reorganisation of these other countries into a common transitional path. This separation into two groups is too slow to be detected over the entire period (1974–2013) but is evidenced if one focuses on the end of the time period. The fact that four outliers (Japan, Portugal, Spain and Italy) are detected is not a surprise. However, their weak performances may be attributed to several factors: a specialisation in low-productivity sectors for Spain, highly protective and anticompetitive regulations in agriculture and services for Japan, low relative education levels for Portugal (7.9 years of schooling on average for the 15–64 population in 2010, while other countries show values ranging from 10.2 in Spain to 13.6 in the USA).

We now take a look at the sensitivity of our clubs to changes in a set of parameters. More detailed results are presented in "Online Appendix D".

4 Robustness and discussion about the club convergence detection

Before turning to the robustness and stability of the different convergence groups identified above, an important point about club convergence must be discussed. The

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[14] The presence of Canada in the group of laggards is not robust and less consistent with the series of LP and GDP per capita. Canada is thus probably the reason for the weak coefficient associated with club 2 in the 1990–2013 period for TFP and is not considered a laggard in the discussion.

methodology presented in Phillips and Sul (2007) and the algorithm described in "Online Appendix C" can only detect groups of countries that converge towards the same steady-state equilibrium. However, they tell us nothing about the underlying factors that explain the existence of multiple equilibria. This question is important: if all of these factors are structural characteristics, and thus if the initial conditions are not significant, then we are probably wrongly interpreting a conditional convergence as a club convergence. It means that countries sharing similar structural characteristics converge to the same steady state. This distinction between these two types of convergence is not only a question of semantics. According to Galor (1996), in the case of conditional convergence, countries that are identical in all characteristics but their initial conditions (they have comparable political systems, population growth rates, levels of technology, etc., but start from different levels of development) will ultimately converge to the same steady state. A transitory shock will have no lasting effect on this convergence process. On the contrary, in the case of club convergence, where initial levels have a significant effect, such a transitory shock could lead the affected country to leave the converging path and either join a new club or diverge. In Bartkowska and Riedl (2012), a similar algorithm based on Phillips and Sul (2007) is used to find club convergence among European regions. To give evidence in favour of the club convergence hypothesis, they use a cross-sectional ordered logit model. The club to which region i belongs is used as a left-hand side variable, while the other side of the equation is composed of a set of structural variables (population density, high-tech production, population growth, etc.) and a set of initial conditions (capital stock per capita, labour force, etc.). They show that the probability of belonging to one group is sensitive to the initial conditions which confirm the club convergence hypothesis. However, because we only have data for 17 countries, such an analysis would be difficult to conduct in our sample. We can, however, benefit from a very large time period which enables us to change the initial date without loss of information. To do so, we focus on GDP per capita and TFP and run the algorithm of club convergence detection after shifting the initial date by more or less 3 years. We then compare the resulting clubs with those found for the regular time period. If clubs are stable, this would provide evidence against the club convergence hypothesis and suggest that the initial level is not crucial in explaining the formation of these groups. On the contrary, if clubs are unstable, the observed change would be in line with our hypothesis of club convergence. Table 3 sums up the results for the periods 1990–2013, 1987–2013 and 1993–2013. Starting with GDP per capita, we can see that group 1 can be broken down into a very stable subgroup of leaders composed of Australia, Canada, Switzerland, Finland, the Netherlands, Norway, Sweden and the USA. These countries are allocated to group 1 irrespective of the change in the starting date. For other groups and other countries, the results are less stable, suggesting that the starting date (and therefore the initial conditions) does matter and that the boundary between these clubs is not very clear. On the contrary, when looking at TFP, the clubs are very stable and indifferent to the initial conditions. The only exception is for the period 1993–2013, where three clubs are detected, but in fact groups 1 and 2 follow the same transitional path as that seen when using a longer time frame.

These differences suggest that for GDP per capita, the convergence club hypothesis seems to hold, and for countries that do not belong to the above-mentioned stable

Table 3 Results when the Phillips–Sul club convergence test is used on the set of 17 countries for GDP per capita and TFP. Comparison of resulting clubs for the periods 1987–2013, 1990–2013 and 1993–2013 quarterly data.

1987-2013	1990-2013	1993-2013
GDP per capita		
Gr1: AU, CA, CH, FI, GB, NL, NO, SE, US	**Gr1:** AU, BE, CA, CH, DE, FI, GB, NL, NO, SE, US	**Gr1:** AU, CA, CH, FI, NL, NO, SE, US
Gr2: BE, DE, DK, ES, FR, JP	**Gr2:** DK, ES, FR	**Gr2:** DE, GB
Gr3: IT, PT	**Gr3:** IT, JP	**Gr3:** BE, DK
	NOCV: PT	**Gr4:** ES, FR, IT, JP
		NOCV: PT
TFP		
Gr1: AU, BE, CH, DE, DK, FI, FR, GB, NL, NO, SE, US	**Gr1:** AU, BE, CH, DE, DK, FI, FR, GB, NL, NO, SE, US	**Gr1:** BE, DE, FR, GB, NL, NO, SE, US
Gr2: CA, ES, IT, JP, PT	**Gr2:** CA, ES, IT, JP, PT	**Gr2:** AU, CA, CH, DK, FI
		Gr3: ES, IT, JP, PT

See Table 1 for details

subgroup of leaders, a transitory shock can change their transitional path. In this case, they can join the group of leaders, as in the case of the United Kingdom, or diverge, as in the case of Portugal. For TFP, the conclusions are different. Given that initial conditions do not seem to matter for the composition of the groups, a transitory shock may not affect countries' transitional path. Consequently, countries that are considered as laggard in terms of TFP, i.e. Japan, Spain, Italy and Portugal, are stuck in a convergence path towards a different steady state than other countries. With these ideas in mind, we now turn to robustness tests. We conducted two kinds of robustness tests to check the consistency and stability of the clubs identified by the Phillips and Sul (2007) algorithm. First, we looked at the assumption made for the construction of our series. In particular, we set the value of , the elasticity of the Cobb–Douglas function, to 0.3 and the depreciation rate to 0.1 for equipment and 0.025 for buildings. In a first robustness check, we relaxed these assumption by allowing to be equal to 0.25 (low value) and 0.35 (high value) and then by setting the depreciation rate to 0.05 for equipment and 0.015 for buildings (low values) and 0.15 for equipment and 0.05 for buildings (high values). Only two series are affected by this change: the TFP and capital intensity series. Next, we looked at the specific assumption made in the algorithm itself and which concerns the initial order of countries and the value of the trimming coefficient r (see "Online Appendix C" for a description of the algorithm). In every case, results are not strongly affected by these changes (see "Online Appendix D"). In particular, global convergence results are always robust.

5 Conclusion

Long-term views on GDP per capita are useful to understand long developments regarding convergence processes in standards of living and economic development. In this study, we use a new database covering the period 1890–2013 for 17 advanced countries and a reconstituted euro area to present comparisons of GDP per capita levels and growth rates across these countries, and a comparison of the level and growth of the main components of GDP per capita through an accounting breakdown. These components are TFP, capital intensity, working time and the employment rate. Convergence tests are also conducted for GDP per capita and its components over different sub-periods. The test methodology is inspired by Phillips and Sul (2007) and is related to the family of σ-convergence tests. The main results are the following: (i) an overall convergence process has been at work among advanced countries, mainly after WWII, first through capital intensity and then through TFP, while trends in hours worked and even more so employment rates are more disparate; (ii) however, this convergence process is not continuous. It has stalled since 1990, as the convergence of the euro area, the United Kingdom and Japan towards the US GDP per capita level stopped at a large distance from the US level, while that of reforming or structurally flexible countries accelerated thanks to ICT. This means that the catching-up process as regards GDP per capita is not always continuous; (iii) other club convergence processes appeared during some sub-periods, mainly in post WWII decades. The employment rate and hours worked are mainly concerned, with continental European countries posting lower levels than Anglo-Saxon countries for these variables. Policies

may influence relative GDP per capita levels. In addition to policies that support innovation, the most relevant policies for influencing the convergence process of GDP per capita are those that increase productivity gains linked to technological shocks and, for example, policies aimed at reducing anticompetitive barriers in the product market or introducing more flexibility in the labour market and, of course, policies aimed at increasing the level of education of the working age population (see on these aspects Aghion and Howitt (1998, 2006, 2008), and Aghion et al. (2009) for an empirical illustration). However, these policies also impact labour supply. On this last aspect, compared to the USA, GDP per capita in the euro area has been adversely affected by lower employment rates in the last decades. The rise in the participation rate in the euro area over the last two decades highlights the important role of policies.

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