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GDP per capita in advanced countries over the 20th century[1]

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Abstract:

This study presents a GDP per capita level and growth comparison across 17 main advanced countries and over the 1890-2013 long period. It proposes also a comparison of the level and growth of the main components of GDP per capita through an accounting breakdown and runs Philips-Sul (2007) convergence tests over GDP per capita and its main components. These components are total factor productivity, capital intensity (capital stock per hours worked), working time and employment rate. Over the whole period, standards of living as measured by GDP per capita experienced a very marked increase in advanced countries, especially because of the surge in Total Factor Productivity (TFP) and in capital intensity.

The main results of the study are the following: i) All countries experienced at least one big wave of GDP per capita growth during the 20th Century, but of different sizes and in a staggered manner; ii) Almost all countries have suffered from a significant decline in GDP per capita growth during the last decades of the period; iii) The GDP per capita leadership changed among large countries over the period, from the UK until WWI to the US since WWII; iv) There is an overall convergence process among advanced countries, mainly after WWII, relying mostly on capital intensity convergence and then on TFP convergence, while evolutions in hours worked and even more employment rates are more disparate; v) But this convergence process is not continuous and was particularly scattered since 1990, as the convergence of the EA, the UK and Japan to the US GDP per capita level stopped at a large distance, with reforming or structurally flexible countries accelerating thanks to the Information and Communication Technology shock, while some countries such as Japan lingered in crisis; vi) Employment rates and hours worked did not contribute to the overall convergence process, with club convergence very often appearing for these variables among European countries on one side and Anglo-Saxon countries on the other. Dynamics were especially divergent between these two groups since 1974, as opposite labor policies were implemented.

JEL classifications: N10, O47, E20

Keywords: GDP per capita, Productivity, convergence, technological change, global history

Résumé :

Cette analyse propose une comparaison du niveau et de l’évolution du PIB par habitant de 17 importants pays avancés sur la longue période 1890-2013. Elle propose également une comparaison du niveau et de l’évolution des principales composantes du PIB par habitant ainsi que les résultats de tests de convergence, utilisant la méthodologie de Philips-Sul (2007), du PIB par habitant et de ses principales composantes. Ces composantes sont la productivité globale des facteurs (PGF), l’intensité capitalistique (volume de capital par heure de travail), la durée du travail et le taux d’emploi. Sur l’ensemble de la période de l’étude, les niveaux de vie appréhendés par le PIB par habitant ont connu une très forte augmentation dans les pays avancés, essentiellement du fait de l’augmentation de la PGF et de l’intensité capitalistique.

Les principaux résultats de l’analyse sont les suivants : i) Dans tous les pays, au moins une grande vague de croissance du PIB par habitant est observée au cours du XXème Siècle, mais avec des ampleurs très contrastées et des décalages parfois importants selon les pays ; ii) Dans presque tous les pays, le PIB par habitant ralentit fortement sur les dernières décennies de la période étudiée ; iii) Le pays leader parmi les plus grands pays industrialisés en termes de PIB par habitant change sur la période , du Royaume-Uni jusqu’à la Première Guerre Mondiale aux États-Unis depuis la Seconde Guerre Mondiale ; iv) Une forte convergence des niveaux de PIB par habitant est observée parmi les pays avancés, surtout après la Seconde Guerre Mondiale, essentiellement expliquée par la convergence de l'intensité capitalistique et de la PGF, tandis que les niveaux de durée du travail et surtout de taux d'emploi demeurent disparates ; v) Mais ce processus de convergence n'est pas continu et devient plus diffus à partir de 1990. La convergence du PIB par habitant de la Zone Euro, du Royaume-Uni et du Japon s'interrompt à une distance encore importante du niveau observé aux États-Unis, les pays structurellement flexibles ou ayant mis en œuvre des réformes institutionnelles importantes bénéficiant d'une accélération associée à la diffusion des Technologies de l'Information et de la Communication, tandis que d'autre pays comme le Japon pâtissent d'une crise prolongée ; vi) Le taux d'emploi et la durée du travail ne contribuent pas à la convergence d'ensemble des niveaux de PIB par habitant et se caractérisent plutôt par des club-convergences, une convergence apparaissant pour ces variables entre les pays européens d'un côté et les pays anglo-saxons de l'autre. Les évolutions sont contrastées entre ces deux groupes de pays depuis 1974, en relation avec la mise en œuvre de politiques très différenciées sur le marché du travail.

Classification JEL : E20, N10, O47.

Mots-clés : PIB par habitant ; Productivité ; Convergence, Changement technologique ; Histoire de la croissance.

Non technical summary

Standard of living comparisons across countries are usually based on GDP per capita indicators. This study presents a GDP per capita level and growth comparison across the main advanced countries and over a long period. It proposes also a comparison of the level and growth of the main components of GDP per capita through an accounting breakdown. These components are total factor productivity, capital intensity, working time and employment rate. Such a breakdown allows characterizing the contributions of these different components to GDP per capita differences across countries. The study also focuses on testing the convergence hypothesis in terms of GDP per capita and its components over different sub-periods.

Our dataset is composed of 17 advanced countries: the ones in the G7 (the United States, Japan, Germany, France, the United Kingdom, Italy and Canada), the other three biggest countries of the Euro Area (Spain, the Netherlands and Belgium), two other countries of this Area (Portugal and Finland) and five other OECD countries interesting for productivity analysis because of some specificities, such as a high productivity level at the beginning of the period for Australia, a particular industry structure for Norway and Switzerland and the role of structural policies for Sweden and Denmark. In addition, a Euro Area has been reconstituted, aggregating Germany, France, Italy, Spain, the Netherlands, Belgium, Portugal and Finland. This approximation seems acceptable as these eight countries represent together, in 2010, 93.2% of the Euro Area GDP (16 countries in 2010). The countries we selected are today "advanced" and so converged at some point in time; hence, global convergence results will not be a surprise but, as we will see, convergence is not a smooth or automatic process. We observe for example that the convergence process to the US GDP per capita level stopped over the last decades in the Euro Area, but also in some specific countries still far from the US level.

The analysis is carried out over the period 1890-2013 on annual data and also, from 1974, quarterly data. The starting database was the one built by Cette, Kocoglu and Mairesse (2009), updated and considerably enlarged in Bergeaud *et al.* (2014), and once more in this study. For this, we have tried to make the best use of national accounting data for the last decades and of the estimates of long aggregate historical data series by economists and historians, in particular Maddison (1994, 2001, 2003), updated by Bolt *et al.* (2013). The data are built at the country level under the hypothesis of constant borders, in their last state. Series for GDP and capital are given in 2010 constant national currencies and converted to 2010 US dollars at purchasing power parity (ppp) with a conversion rate from the Penn World Tables. This data building requires strong assumptions to reconstitute some countries and series. We may nevertheless consider that the orders of magnitude of our estimates and the ensuing large differentials in GDP per capita levels and growth rates are fairly reliable and meaningful.

The test methodology is inspired by Phillips and Sul (2007), this methodology being related to the family of σ-convergence tests. This methodology offers many advantages in addition to being a "simple regression based convergence test" (Phillips and Sul, 2007). First, it allows analyzing comovements and convergence even in the case of cross-sectional heterogeneity when cointegration tests are no longer useful. Second, with the same test, it enables to distinguish between global convergence, divergence or club convergence across different economies.

The main originalities of the analysis are that it is presented over a long period, on a large set of countries, with data reconstituted in purchasing power parity and on the basis of, as much as possible, consistent assumptions.

This study leads to numerous results regarding GDP per capita level, evolution and convergence. The main ones are the following: i) All countries experienced at least one big wave of GDP per capita growth during the 20th Century, but in a staggered manner. The size of the wave seems related to the starting level: it was the strongest in Japan, but from the lowest initial GDP per capita level, and the lowest in the UK, but from a higher level than the EA and Japan. The EA is in an intermediate position: a medium wave and a medium starting level; ii) Almost all countries have suffered, during the last decades of the period, from a huge decline in GDP per capita growth; iii) The GDP per capita leadership changed over the period: the UK was the leader until WWI and for some years during the Great Depression, but US has maintained its leadership since WWII. It makes it interesting to analyze the reasons for these leadership changes; iv) There is an overall convergence process among advanced countries, mainly after WWII, first through capital intensity and then TFP, while evolutions in hours worked and even more employment rates are more disparate; v) But this convergence process is not continuous. For example, it was particularly scattered since 1990, as the convergence of the EA, the UK and Japan to the US GDP per capita level stopped at a large distance from the US level, with reforming or structurally flexible countries accelerating thanks to the Information and Communication Technology shock, while some countries such as Japan lingered in crisis. This fact was already identified in the literature (see for example Crafts and O'Rourke, 2013) and means that the GDP per capita catch-up to the leadership position is not always an ongoing process; vi) Employment rates and hours worked did not contribute to the overall convergence process, with club convergence very often appearing for these variables among European countries on one side and Anglo-Saxon countries on the other. Dynamics were especially divergent between these two groups since 1974, as opposite labor policies were implemented

Policies may influence the relative GDP per capita levels. Apart from policies supporting innovations, the most relevant ones to influence the convergence process of GDP per capita are the ones which allow the faster productivity benefit from technological shocks, and for example policies reducing anticompetitive barriers on the product market, or introducing more flexibility on the labor market, and of course policies increasing the education level of the working age population (see on these aspects Aghion and Howitt, 1998, 2006, 2009, and Aghion *et al*. 2009 for an empirical illustration). But they are also policies impacting labor supply. On this last aspect, compared to the US, the GDP per capita in the EA suffers in the last decades from lower employment rates. The increase of the participation rate in the EA over the two last decades illustrates the large role of policies.

1. Introduction

Standard of living comparisons across countries are usually based on GDP per capita indicators. This choice is of course simplistic: it considers only a particular economic development measure, excluding many dimensions influencing the citizen well-being, for example the trade-off between work and income on one side and leisure on the other, the inequalities in income distribution, the sustainability of development and growth,… These lacks have inspired an abundant literature, and the Stiglitz, Sen and Fitoussi (2009) report proposed several ways to enrich the economic and social development measure. These proposals are progressively taken into account[2] but, in the current situation of a lack of consensual and homogeneous indicators available on a large set of countries, country comparisons of economic development focus usually on GDP per capita indicators.

The abundant literature devoted to GDP per capita country comparison has mainly focused on two non-independent questions: convergence of GDP per capita across countries and factors explaining growth in GDP per capita (see Islam, 2003, for a synthesis). It appears that GDP per capita levels do not necessarily converge across countries, even advanced ones (see for example the seminal papers from Baumol, 1986, or Barro, 1991). In other words, low GDP per capita countries do not necessarily catch up with high GDP per capita ones, and the gap may even increase over long period of time. The literature has put forward numerous factors of GDP per capita growth and convergence. Catching-up will rely on the “social capability” to adopt new technologies and on “technological congruence” making it cost effective to adopt leader’s technology (Abramovitz and David, 1995). “Social capability” gives a particularly important role to institutional and educative factors (see for example Barro, 1991, Barro and Sala-I-Martin, 1997, Hall and Jones, 1999, and, for recent evaluations, Aghion *et al.*, 2008, or Madsen, 2010a and 2010b). Institutional factors correspond for example to property rights, labour and product market regulations, financial system development and regulations, juridical system quality and even democracy, as shown by Acemoglu *et al.* (2014)… Education corresponds to the education level of the working age population. Innovations and technical progress depend on these institutional and educative factors (see Aghion and Howitt, 1998, 2006 and 2009). Craft and O’Rourke (2013) even suggest that the role of institutional factors could have increased over the last decades. Some specific institutions such as the tax system may also influence the leisure-work trade-off and for this reason may explain some cross-country differences in terms of working time or participation rates which contribute to differences in country GDP per capita (see for example Prescott, 2004, for a Europe-US comparison). “Technological congruence” relates to Acemoglu’s “Directed technical change” (1998, 2002), which emphasizes that technical change is determined by relative factor endowment and market size. Regarding the United States, Gordon (2012, 2013, 2014) points that “six headwinds” are already in action to slow down GDP per capita growth and could play a larger role in the future. These headwinds are: i) A reversal of the demographic dividend; ii) A plateau in educational attainment; iii) Rising income and wealth inequalities; iv) Globalization; v) Energy and environment risks; vi) Twin household and government deficits. In the other advanced countries, some of these six headwinds are already at play or will soon start to be.

This study presents a GDP per capita level and growth comparison across the main advanced countries and over a long period. It proposes also a comparison of the level and growth of the main components of GDP per capita through an accounting breakdown. These components are total factor productivity, capital intensity, working time and employment rate. Such a breakdown allows characterizing the contributions of these different components to GDP per capita differences across countries. The study also focuses on testing the convergence hypothesis in terms of GDP per capita and its components over different sub-periods.

[2] See for example the empirical country comparison through a large set of indicators proposed by Fleurbaey and Gaulier (2009).

According to Galor (1996), three different concepts of convergence exist: First, the absolute convergence hypothesis entails that GDP per capita converge to a common steady state equilibrium over the long-run, no matter what their initial conditions were. Second, the conditional convergence hypothesis also supposes this convergence to a common steady state independently of initial levels, but only among countries that share common structural characteristics (demography, policy, geography…). 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 steady states 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). How to test for one of these three types of convergence has been a widely discussed topics since Barro and Sala-i-Martin (1991, 1992 and 1995) seminal works. Two approaches, the β- or the σ-convergence, are usually emphasized. 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. The club-convergence hypothesis has been first tested using the β-convergence method (see Durlauf and Johnson, 1995 for an example and Bartowska and Riedl, 2012, for a review). This approach has its limitation since it requires to identify *a priori* the factors that can explain the existence of multiple *equilibria* and to preselect groups of countries according to these criteria. In order to avoid making such arbitrary choices, more recent methods has been developed to endogenize 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" (Phillips and Sul, 2007). First, it allows analyzing comovements and convergence even in the case of cross-sectional heterogeneity when cointegration tests are no longer useful. Second, with the same test, it enables to distinguish between global convergence, divergence or club convergence across different economies.

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Section 2 presents the dataset. Section 3 proposes a first descriptive analysis of GDP per capita waves and convergence on the United States, the Euro Area, the United Kingdom and Japan. Section 4 enlarges this descriptive analysis on the whole set of countries and on GDP per capita and its main components through an accounting breakdown approach. Section 5 presents Philips and Sul (2007) convergence tests on GDP per capita and its components, over different sub-period. Section 6 concludes.

2. The data[3]

In order to build series for GDP per Capita and to conduct its decomposition, we needed few series but over a long period for the 17 considered advanced countries. These 17 countries correspond to the ones in the G7 (the United States, Japan, Germany, France, the United Kingdom, Italy and Canada), the other three biggest countries of the Euro Area (Spain, the Netherlands and Belgium), two other countries of this Area (Portugal and Finland) and five other OECD countries interesting for productivity analysis because of their specificities: a high productivity level at the beginning of the period for Australia, a particular industry structure for Norway and Switzerland and the role of structural policies for Sweden and Denmark. In addition, an Euro Area has been reconstituted, aggregating series of Germany, France, Italy, Spain, the Netherlands, Belgium, Portugal and Finland.

[3] See Appendix A for further details about data construction, updates and sources.

This approximation seems acceptable as these 8 countries represent together, in 2010, 93.2% of the Euro Area GDP).[4]

The analysis is carried out over the period 1890-2013 on annual data and also, from 1974, quarterly data. The starting database was the one built by Cette, Kocoglu and Mairesse (2009) on the United States, Japan, France and the United Kingdom over the 1890-2006 period. Bergeaud, Cette and Lecat (2014) have updated and considerably enlarged this first database to a total of 13 countries. For this study, we added four countries to the dataset (Belgium, Denmark, Portugal and Switzerland) and updated the series up to 2013, taking into accounts recent changes in national accounting methodologies.

To compute GDP per capita indexes over this long 1890-2013 period, we rely on Maddison (2001) whose series have been updated by Bolt *et al.* (2013). Maddison provides data for GDP (*Y*) and population (*P*), most of the time from 1820. We supplemented these data with national accounts data. For other series and in particular to compute the total factor productivity index (*TFP*) used in the accounting breakdown of the GDP per capita, three basic series are needed for each country: employment (*N*), hours worked (*H*) and capital (*K).* The capital indicator is constructed by the perpetual inventory method (PIM) applied to each of the two components (equipment *KE* and buildings *KB*) thanks to the corresponding investment data (*IE* and *IB*). The yearly depreciation rates used to build the capital series by the PIM are 10.0% for equipment and 2.5% for buildings following Cette, Kocoglu and Mairesse (2009) and are assumed to be constant across time and space. Finally, damages happening during WWI, WWII, earthquakes in Japan and the civil war for Spain are, as much as information is available for this, taken into account to build the capital series.

For long aggregate historical data series, we used data built by economists and historians on consistent assumptions. Many of these data are subject to uncertainty and inaccuracy, not only for the most distant periods but also for recent ones. The data are built at the country level under the hypothesis of constant borders, in their last state. It should be noted that however talented economists and historians are, strong assumptions are required to reconstitute some countries.[5] We may nevertheless consider that the orders of magnitude of our estimates and the ensuing large differentials in GDP per capita and productivity levels and growth rates are fairly reliable and meaningful. Series for GDP and capital are given in 2010 constant national currencies and converted to US dollars at purchasing power parity (ppp) with a conversion rate from the Penn World Tables. Differences in GDP level may be significantly affected by the basis year of the PPP conversion rate used, as it reflects the GDP structure at a specific date in history.

GDP per capita is the ratio of the GDP divided by the population (*Y / P*). The employment rate is the ratio of the employment divided by the population (*N / P*). We consider two productivity indexes: Labor Productivity (denoted *LP*) and Total Factor Productivity (denoted *TFP*).

The labor productivity indicator (*LP*) is the ratio of GDP (*Y*) to labor (*L*): $LP = Y / L$. Labor 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*): $L = N * H$. Labor is considered homogeneous.

Labor productivity (*LP*) is itself decomposed in two sub-components, following Solow's "growth accounting approach" (Solow, 1956, 1957): the total factor productivity (*TFP*) and the capital to labor ratio (*K / L*) powered by the elasticity of GDP to capital (α). The capital to labor ratio is named capital intensity and its growth corresponds to the capital deepening mechanism. The total factor

[4] The Euro Area is composed by 16 counties in 2010.

[5] Consider for example the distance of these hypothetical constant border countries from the economic reality for Germany and even Italy and France over the period 1890-2013.

productivity indicator (*TFP*) is the ratio of GDP (*Y*) to an aggregation function $F(.)$ of the two considered production factors, capital (*K*) and labor (*L*): *TFP = Y / F(K, L)*. Capital is here 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: $TFP = Y / (K^{\alpha} * L^{\beta})$, where α and β are the elasticities of output with respect to the inputs *K* and *L*. Assuming unitary returns to scale ($\alpha + \beta = 1$), the relation becomes: $TFP = Y / (K^{\alpha} * L^{1-\alpha})$. We take as the measure of capital (*K*) in use in the period *t* the volume of the stock of capital installed at the end of the period $t - 1$. The *TFP* term stands for the impact on growth of autonomous technical progress and of other unmeasured factors, and is usually evaluated as a residual, while the other components of the equation are individually computed. It is important to note that the improvement in the quality of labor through education, better health, *etc.* is included in this *TFP* term, as our labor input reflects solely the number of hours worked. More generally, the role of TFP in convergence may be overestimated due to unmeasured inputs (education, intangibles), inputs quality and economies of scale.

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 ($\alpha + \beta = 1$), 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 labor 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.

Finally, it is important to note that, in our model, we do not consider human capital so that the impact of education is included in *TFP*. In what follows, one should keep in mind that *TFP* does not only encompass technology but is a residual of every variation of labor productivity that is not captured by capital intensity. As developed below, we estimate that around 20% of this residual can be attributed to human capital.

3. GDP per capita growth waves and convergence

From 1890 to 2013, the GDP per capita increased, in average per year, by 2.1% in the US and the Euro Area (EA), 1.9% in the United Kingdom (UK) and 2.9% in Japan, from different starting levels. Nevertheless, this growth was irregular and very heterogeneous across countries. Over the long period 1890-2013, numerous global shocks occurred, such as WWI and WWII, technological and industrial revolutions, supply world shocks as petrol price ones, and the two financial crises, the Great Depression and the Great Recession. Numerous large idiosyncratic shocks also occurred, such as the Spanish Civil War during the 1930s, the Swedish financial crisis at the end of the 1980s, the Finnish economic crisis at the early 1990s or the implementation of ambitious structural reform programs during the 1990s in Australia, Canada, Finland or Sweden. Because of these shocks, the GDP per capita growth appears very volatile. For this reason, we start by characterizing the main waves of GDP per capita and convergence processes over the long 1890-2013 period, for the US, the EA, the UK and Japan.

In order to establish the stylized facts of GDP per capita growth, we smooth the annual growth rate over the period using the Hodrick-Prescott filtration (HP). Considering the very high volatility of our data, the choice of the lambda coefficient, which sets the length of the cycle we capture, is of paramount importance. Setting too high a value for lambda would tend to absorb smaller cycles, while setting too low a value would result in major cyclical effects being considered to be trends, especially around WWII. We decided to focus on 30-year cycles, which implies a value of 500 for lambda, according to the HP filter transfer function.

Chart 1 represents the distance with the US GDP per capita level for the EA, the UK and Japan. Chart 2 represents smoothed GDP per capita growth, from 1890 to 2013, for the same regions and the US.

Concerning GDP per capita levels, a first observation is that the leadership changed over the period: the UK was the leader until WWI and for some years during the Great Depression, but US has kept the leadership position since WWII. It means that a leadership position has not to be considered as necessarily definitive, and it makes it interesting to analyze the reasons of these leadership changes. A second observation is that there is not a continuous convergence process towards the highest GDP per capita level among advanced countries. Indeed, technologies developed in one country may be inappropriate in another: the US developed technologies adapted to a large domestic market and relative labor scarcity, which did not fit inter-war Europe's characteristics (Abramovitz and David, 1995). A large divergence process has taken place during WWII, which will be explained later by the differing impacts of the conflict on *TFP* and capital intensity, depending on the fact that the conflict happened or not on the own soil of the considered country or area. But, more impressive perhaps, it appears that the convergence process of the EA, the UK and Japan to the US GDP per capita level stopped, during the last three decades, at a large distance from the US level (15% to 30%). This fact, already identified in the literature (see for example Crafts and O'Rourke, 2013) means that the GDP per capita catch-up to the leadership position is not always ongoing and on the contrary can stay unachieved for long. It makes it interesting to analyze the reasons for this incomplete process and to offer some answers to the question: why the EA, the UK and Japan seem condemned to suffer for so long from a lower GDP per capita level than the US?

Concerning GDP per capita growth, a first observation is that the four considered areas experienced at least one big wave of GDP per capita growth during the 20th Century, but in a staggered manner: first the US in the 1930s and 1940s, followed by the EA, the UK and Japan, with at least a two decade delay, after WWII. The size of the wave seems related to the starting level: it was the strongest in Japan, but from the lowest initial GDP per capita level, and the lowest in the UK, but from a higher level than the EA and Japan. The EA is in an intermediate position: a medium wave and a medium starting level. A second observation is that the four considered areas have suffered, during the last decades of the period, from a huge decline of the GDP per capita growth. At the end of the period, the GDP per capita growth is lower than 1%, an unprecedented situation since WWII for the EA, the Great Depression for the US and WWI for the UK.

We will see later that these GDP per capita long waves are mainly driven by the *TFP* ones, which seem quite similar (see Bergeaud, Cette and Lecat, 2014, for more details). In the US, the GDP per capita growth waves correspond for a large part to the major technological revolutions:

- The end of the first industrial revolution at the beginning of the period. This first revolution was associated to the diffusion of the stream engine, to the development of the railways, *etc*;

- The second industrial revolution, which corresponds mainly to the diffusion of a massive use of electricity and of the internal combustion engine, to the development of chemistry with petrochemistry and pharmaceuticals, and to the development of communication and information innovations (telephone, radio, cinema), *etc*;

- The third and last revolution associated to the diffusion of the information and communication technologies (ICT). It appears in the 1980s and the 1990s. The slowdown of the impact of ICT on productivity since the early 2000s, before the Great Recession, is largely debated. Some analyses consider it as structural (see for example Gordon 2012, 2013) and others as a short step before a new acceleration and even partly as mismeasurement (see for example Byrne, Oliner and Sichel, 2013). Other explanations of this slowdown are also plausible (for a survey see Cette, 2014).

In the EA and Japan, the latest wave of GDP per capita growth is less apparent than in the US, and for this reason the GDP per capita level declines since the early 1990s, relatively to the US level. In the UK on the contrary, the last GDP per capita growth wave is more apparent than in the US, and the GDP per capita restarts since the late 1970s a catching-up process to the US level, this process being nevertheless stopped and even reversed during the Great Recession. These differences are largely related to ICT diffusion, more advanced in the US and the UK than in the EA and in Japan (see Cette and Lopez, 2012).

One usual question dealt in the literature consists to ask why the US benefits before other advanced countries from the positive impact of technological revolutions. The answer is usually that this benefit crucially requires adapted institutions as for example an efficient financial system, pro-competitive product market regulation (barriers to entry, price control…), labor market flexibility, high education level of the working age population… (see the analysis of Ferguson and Washer, 2004). The delay observed in the EA and Japan and even the UK, compared to the US, to benefit completely from the positive impact of technological revolutions, is then explained by the delay in institution adaptation to these new technological conditions.

But the impact of institutions is not limited to the one on *TFP*. Institutions impact also largely the employment rate, the working time and even the capital intensity, all these variables being influential on GDP per capita (see on all these aspects Crafts and O'Rourke, 2013). And we will see in the next two sections that these variables contribute also to explain country differences in GDP per capital level and changes over time.

Chart 1
Ratio of GDP per capita in Euro Area, Japan and the United Kingdom with respect to the USA
1890-2013 - $ 2010 ppp – US level = 100 – In %

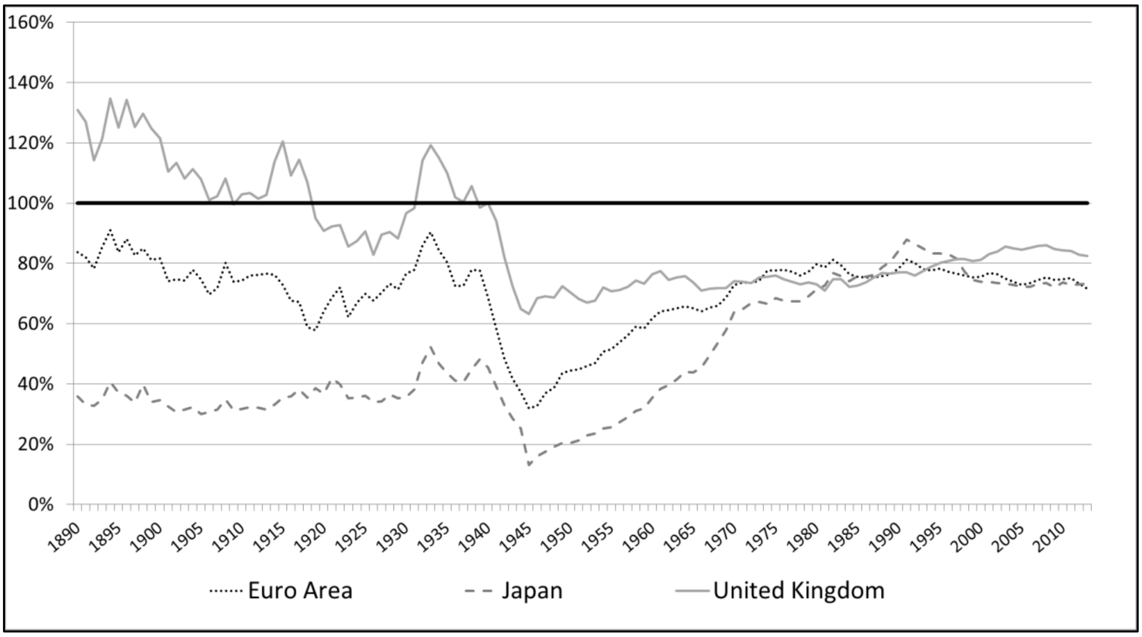
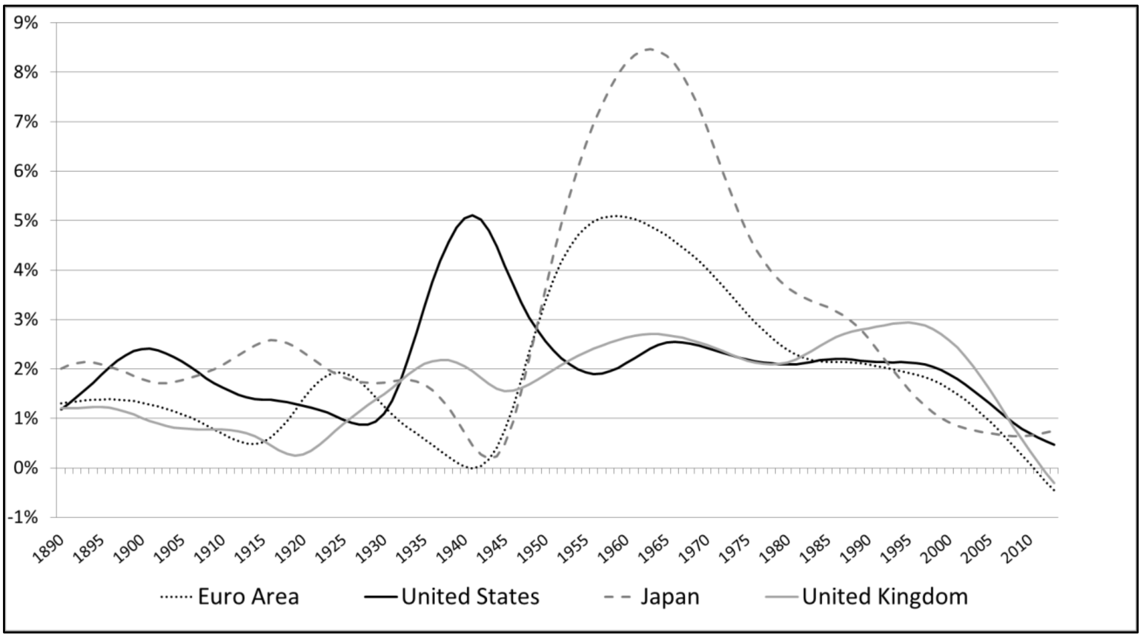


Chart 2

Smoothed (by Hodrick-Prescott filtering[6]) annual growth of GDP per capita in the United States, the Euro Area, the United Kingdom and Japan

1890-2013 – In %



4. GDP per capita convergence: a growth-accounting perspective

The long considered 1895-2013[7] period has been an episode of exceptional economic growth, with GDP per capita multiplied from about 7 in Australia and in UK and up to 23 in Japan. As can be seen in the top left graph of Chart 4,[8] this corresponds to a GDP per capita annual average growth of 1.6% for UK and Australia to 2.6% for Japan.

The main contribution to this long growth episode came from total factor productivity (*TFP*) with an average contribution between 1.2 and 1.9 percentage point (for details about the growth decomposition methodology, see Box 1), as the period has seen major innovations waves in technology, production process, management and finance. However, this TFP indicator also encompasses some evolutions that could be attributed to labor or capital such as improvements in labor quality through education or in capital quality through embodied technologies. The second contributing factor is capital intensity, with a contribution between 0.5 and 1.5 percentage point. It makes up for most of the differences in GDP per capita growth across countries, with a much larger contribution in countries starting from a low GDP per capita level such as Japan or Portugal. Hours per employee posted a negative contribution in all countries over the whole period (between 0.4 and 0.7 percentage point), but also in most sub-periods[9]. Indeed, in all countries, productivity gains have been partly used to obtain more leisure as well as more GDP per capita. Employment rate has posted

6 We have chosen the HP filter parameter value: $\lambda = 500$. In addition, to avoid the issue of extreme value at the beginning of the sample, the filter has been used over the period 1870-2013.

7 Because data from 1890 to 1895 are very volatile, we decide for the remaining sections to consider the series from 1895. This volatility is particularly strong in Australia where the GDP per capita decrease by about 22% between 1890 and 1895.

8 The different periods were chosen on the basis of breaks in productivity trends in Bergeaud *et al.* (2014).

9 Ramey and Francis (2009) showed for the United States that the overall increase in leisure over the last 100 years corresponds to 4 or 5 hours per week, while a large part of the decline in hours per capita is due to improvement in education.

a negative or positive contribution to GDP per capita growth over the whole period, depending on the country, but always limited in size. Its contribution has been negative in most Euro Area countries and positive in most Anglo-Saxon countries.

In our model, the contribution to growth of human capital is included in the *TFP,* which is computed as a residual. Over such a long period, it is hard to find reliable data on education attainment to compute a yearly estimate of human capital for our 17 countries. However, Morrisson and Murtin (2009) provide decennial estimates of average years of schooling among the population aged 15 to 64 for a large set of countries. Through a classic Mincerian human capital function of the form: $H = exp(\theta.s)$, to specify the education contribution to productivity, where s stands for the average length (in years) of education, it is possible to consider the share of this *TFP* residual which could be attributed to education. With an elasticity θ of 7%, which is a common assumption for OECD countries (see Psacharopoulos, 1994, for a review of different values of return to education), we can estimate that over the whole period, human capital accounts for around 20% to 30% of the residual in the countries of our dataset. This contribution is large, but about 2/3 of our *TFP* residual stays unexplained and could be related to many other factors mentioned in the introduction, such as, for example, institutions, innovations and technological shocks.

As can be seen from the top left graph of chart 3, in 1895, the United States were not the GDP per capita leader, as they were overcome by Australia, followed by Switzerland, The Netherlands, the United Kingdom and Belgium. The Australian leadership was due both to its sectoral specialization in mining and to the composition of its population (Mc Lean, 2007), while the Swiss, Belgian and Dutsch advance was related mainly to their employment rates, their productivity level being at that time lower than the US' (see Bergeaud *et al.*, 2014). For Switzerland, this advance over the United States lasts until 1998, partly reflecting the significant share of cross-border commuters in the workforce, which mechanically increases the employment rate. The UK advance is related to the higher share of agriculture in the United States despite a more productive manufacturing sector, resulting in a lower overall *TFP* level (see Broadberry, 1997, Broadberry and Irwin, 2006). Compared to the other countries in our sample, the United States were also penalized by a lower employment rate but were leading in terms of capital intensity.

From 1895 to 1913, GDP per capita growth was the fastest in the United States, Sweden and Canada, relying mainly on *TFP* growth and, for the United States, on increase in employment rate, as immigration added working-age employees to the population. Hence, in 1913, the US GDP per capita has caught up with the UK's, with similar employment rates, lower TFP but higher capital intensity.

1913 to 1950 is a period of great turbulences, with two world wars, the Great Depression and a major innovation wave in the United States (Gordon's "*one big wave*", 1999). World wars tended to benefit to countries not experiencing fights on their soils, as belligerents' demand accelerated innovation diffusion, while production was disrupted and capital destroyed in countries at wars (Bergeaud *et al*., 2014). Hence, the United States experienced one of the fastest growths of all during this period, relying mostly on *TFP* improvement. It is noteworthy that, during the 1910-1950 period, average years of schooling in the US among the population aged 15-64 increased from 7.5 to 9.6, while it only moved from 7.4 to 8.3 in France. This improvement in human capital is very striking for tertiary education which remains flat and very low in almost every countries, but tripled in the US. In 1950, they took the lead in GDP per capita (apart from Switzerland), but also in TFP (apart from Canada and Australia) and capital intensity. On the contrary, the contribution of labor (hours per employee and the employment rate) was generally unfavorable to them.

Box 1

Accounting breakdown of GDP per capita

GDP per capita can be split in the following way:

$$(1)\quad \frac{Y}{P} = \frac{Y}{K^{\alpha}(N.H)^{1-\alpha}} \cdot \left(\frac{K}{N.H}\right)^{\alpha} .H \cdot \frac{N}{P}$$

Where *Y* is the GDP in constant prices, *P* the total population, *N* the number of workers, *H* the average hours worked per year and per worker (so that *L = N*) *.H* is the total hours worked per year) and *K* the capital stock in constant prices.

The coefficient α stands for the elasticity of GDP with respect to capital in a classic Solow framework with a constant returns to scale Cobb-Douglas production function. Under the assumption of perfect competition, it is generally assumed that production factors are remunerated at their marginal cost. It is thus possible to calculate the output elasticities of factors on the basis of the share of their cost on total cost: $\alpha = \frac{rK}{Y}$ with *r* representing the rental cost of capital. In most industrial countries, the value of α is estimated around 0.3.We assume here for all countries and over the all periods $\alpha = 0.3$.

Equation (1) can be rewritten:

$$(2)\quad \frac{Y}{P} = TFP.KI^{\alpha}.H \cdot \frac{N}{P}$$

With $TFP = \frac{Y}{K^{\alpha}.(N.H)^{1-\alpha}}$ being the total factor productivity, $KI = \frac{K}{N.H}$ the capital intensity and $\frac{N}{P}$ the rate of employment over total population.

In this relation (2), GDP per capita $(\frac{Y}{N})$ is decomposed in four elements: i) the *TFP*; ii) the capital intensity powered by α (KI^{α}); the number of hours (H); and the employment rate $\left(\frac{N}{P}\right)$.

From this accounting breakdown, it is possible to decompose the growth rate of GDP per capita by differentiating the logarithm of the previous relationship:

$$(3)\quad \Delta\left(\frac{y}{p}\right) = \Delta(tfp) + \alpha.\Delta(ki) + \Delta(h) + \Delta\left(\frac{n}{p}\right)$$

Where *x* stands for the logarithm of variable *X* (*x = log(X)*) and Δx is an usual approximation for the growth rate of *X*. This relationship is used in charts 4.

We use the operator $\Delta^{US}(X)$ which calculates the relative distance between country *i* and the US for variable X: $\Delta^{US}(Xi) = \frac{X^i}{X^{US}} - 1$.

Suppose now that X is the product of other variables, $\Delta^{US}(X)$ can be decomposed as follow (we drop the index *i* to make the relation lighter):

If X is equal to A.B: $\Delta^{US}(X) = \Delta^{US}(A) + \Delta^{US}(B) + \Delta^{US}(A).\Delta^{US}(B)$.
If X is equal to A.B.C: $\Delta^{US}(X) = \Delta^{US}(A) + \Delta^{US}(B) + \Delta^{US}(C) + \Delta^{US}(A).\Delta^{US}(B) + \Delta^{US}(A).\Delta^{US}(C) + \Delta^{US}(B).\Delta^{US}(C) + \Delta^{US}(A).\Delta^{US}(B).\Delta^{US}(C)$.

And this can be extended to any number of variables. In all cases, $\Delta^{US}(X)$ appears to be the sum of the relative distance for each variable and a corrective term of order 2 and more. When country *i* is close to the US as far as *X* is concerned, the correcting term should be very small and $\Delta^{US}(X)$ can then be proxied by the sum of the relative distance for each variable. However, in our case, this approximation would be unrealistic because some countries (e.g. Japan, Portugal) suffer from a very large distance from the US GDP per capita and its components during most sub-periods.

All in all, the breakdown of relative distance for GDP per capita with the US can be written:

$$(4) \quad \Delta^{US}\left(\frac{Y}{P}\right) = \Delta^{US}(PGF) + \Delta^{US}(KI) + \Delta^{US}(H) + \Delta^{US}\left(\frac{N}{P}\right) + CORR$$

Where *CORR* is the correcting term defined above. This is the relationship that is used to compute charts 3.

From 1950 to 1974, GDP per capita laggards experienced the fastest growth of the century, as they adopted US technologies and production processes. Growth reached about 7% in Japan and close to 5% in the Euro Area, heavily relying on *TFP* and to a lesser extent on capital intensity. The contribution of labor was limited, with a negative contribution of hours worked and an uneven but small contribution of the employment rate. In 1974, the United States remains the GDP per capita leader (apart from Switzerland), but with a smaller lead in *TFP* or capital intensity, while labor contribution is still unfavorable to them. During this period, most European countries and Japan largely increased their stock of human capital to approach the US level. On the meantime, Portugal, Spain and Italy remained at a very low level, with more than 2 years on average behind the frontier. Once again, one focusing on tertiary education figures, the US is by far the leader with more than twice the average duration of the UK, and more than three times the level of European countries.

From 1974 to 1990, GDP per capita slowed down as the catching-up process lost its momentum and two oil shocks disrupted the production processes. It translated mostly into a *TFP* slowdown. In the United States, the contribution of labor turned positive, as employment rate posted a significant positive contribution to growth, while many Euro Area countries implemented policies aiming at reducing labor force participation. In 1990, *TFP* or capital intensity convergence with the United States was almost completed for many Euro Area countries[10], the difference hinged mostly on the contribution of labor, both for hours per employee and the employment rate. These different labor contributions triggered a large debate in the economic literature. According to Prescott (2004), the European tax system discouraged labor supply, while collective preferences for leisure explain lower labor supply for Blanchard (2004). For Freeman and Schettkat (2005), this divergence hinges mainly on women participation rate and reflects an easier substitutability between domestic labor and market services in the United States. For Alesina *et al.* (2005), the lower labour supply in Europe compared to the US results also from employee union interventions, which impose leisure preferences to workers and firms. Convergence in *TFP* with the United States does not necessarily entail that the production process in Euro Area countries reached the US performance standard, as there are decreasing returns to hours worked or to the employment rate (Bourlès and Cette, 2007): the lower contribution of labor in the Euro Area means that employment is concentrated on the most productive workers working shorter hours, which boosts their *TFP* levels. For Japan, this is the opposite situation: *TFP* and capital intensity convergence has not yet been reached but the contribution of labor is higher.

[10] Norway even overcame the United States' GDP per capita level, as the petrol price increase made it profitable for this country to extract oil on a large scale from its continental shelf and consequently this country has benefited from the development of this highly capital intensive and highly productive activity.

Chart 3

Decomposition of GDP per capita level with respect to the USA for 16 countries and the Euro Area

List of countries or region (from left to right): Euro Area (EA), Japan (JPN), United Kingdom (GBR), Germany (DEU), France (FRA), Italy (ITA), Spain (ESP), The Netherlands (NLD), Belgium (BEL), Portugal (PRT), Finland (FIN), Sweden (SWE), Norway (NOR), Switzerland (CHE), Denmark (DNK), Australia (AUS), Canada (CAN).

In % - 2010 USD PPP

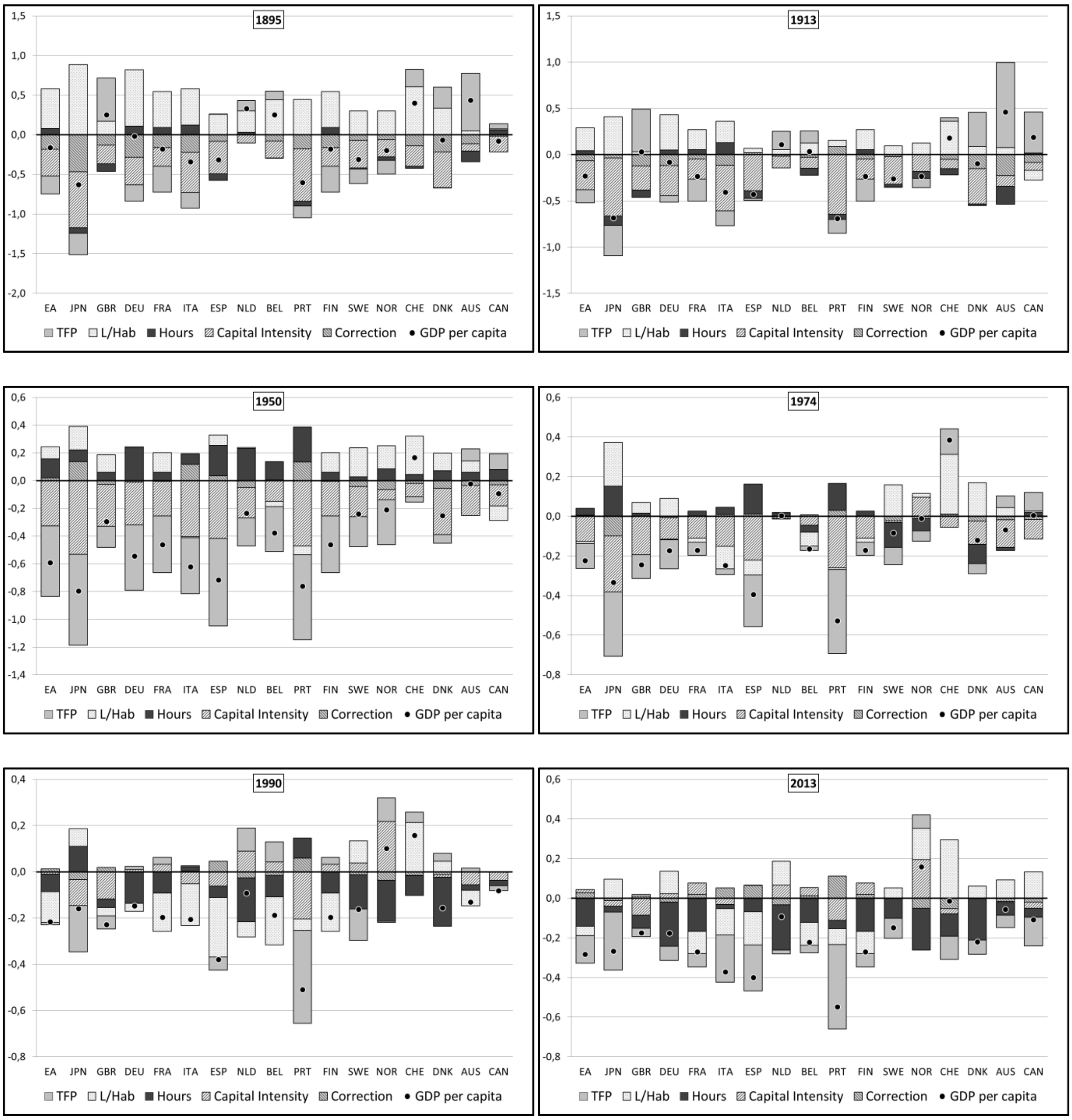
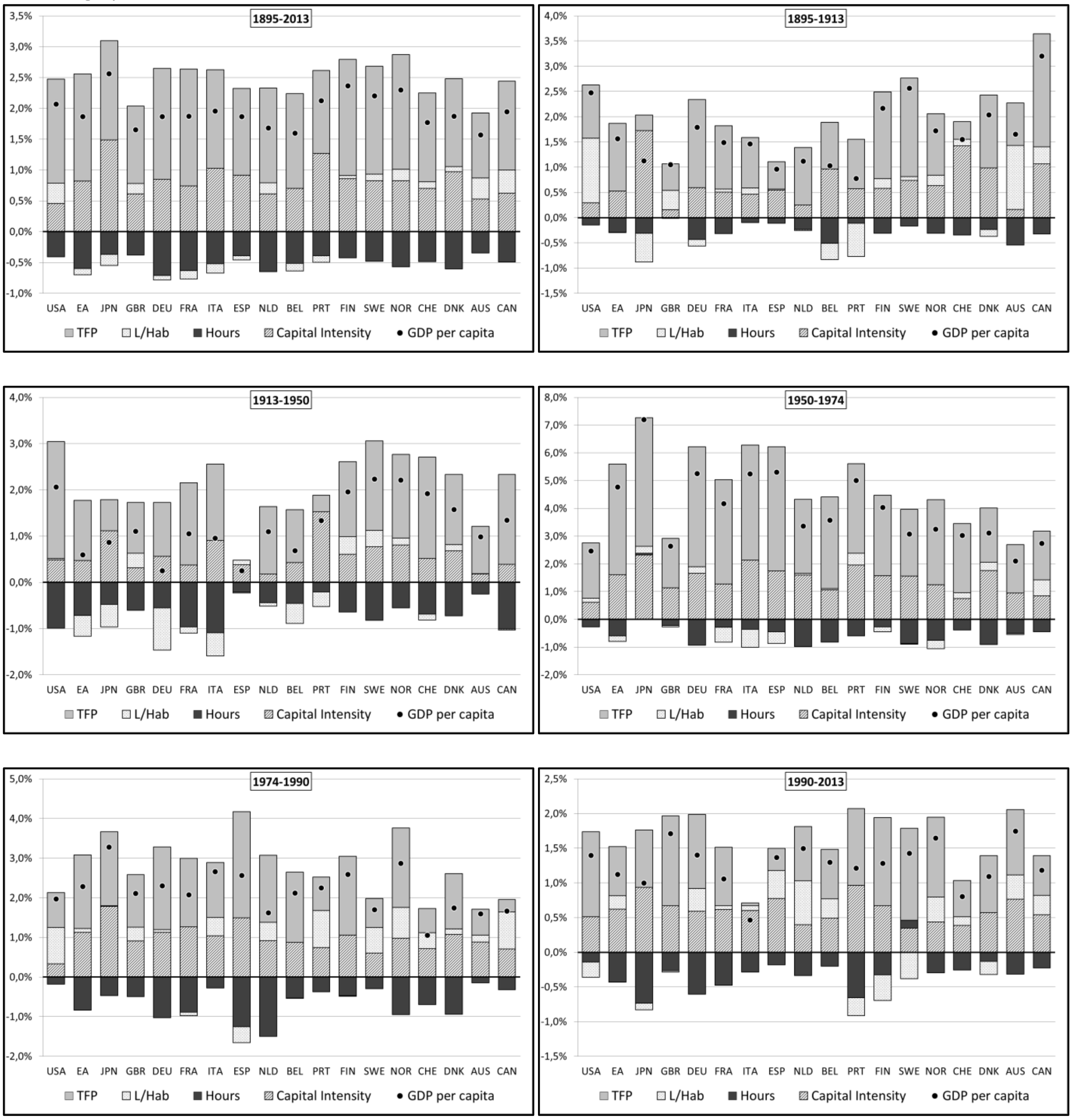


Chart 4

Decomposition of GDP per capita growth for 17 countries and the Euro Area

The list of countries and the order are the same as in Chart 3 to which the US are added.

Percentage points



From 1990 to 2013, GDP per capita growth slowed almost everywhere below 1.5% per year, but for various reasons. In the United States, *TFP* and capital intensity accelerated because of the ICT revolution, as pointed out first by Jorgenson (2001). However, employment rate contribution turned negative, as long-term supporting trends, such as the increase in women participation rate, were exhausted. In the Euro Area, *TFP* growth slowed down, while employment rate contribution turned positive. Indeed, labor market policy reversed to foster labor market participation, leading to an increase in the participation of unskilled workers. In Japan, the financial crisis took its toll and led to a decrease in *TFP* and capital intensity growth rate. As a result of these changes, GDP per capita convergence with the United States halted for the Euro Area and Japan, but went on for countries which implemented structural reforms such as Australia (Parham, 2002), the Netherlands with the Wassenaar agreements between social partners (Visser and Hemerijck, 1998), Sweden with structural reforms of the State but also of the product and labor markets (Edquist, 2011), the United Kingdom with the Thatcher reforms (Card and Freeman, 2002). As a result, in 2013, GDP per capita levels relative to the United States regressed for many Euro Area countries and Japan as the *TFP* gap increased, while employment rate contributed less to this gap in the Euro Area. During this period, the US has reached a plateau in terms of secondary schooling while other countries are still catching up. By the end of the period, most countries have a comparable stock of human capital if we exclude tertiary education. For this level of education, the US still display a large advance with almost 2 years of schooling on average for the population aged 15 to 64 years. At the opposite side, southern European countries, and especially Portugal, are still lagging behind.

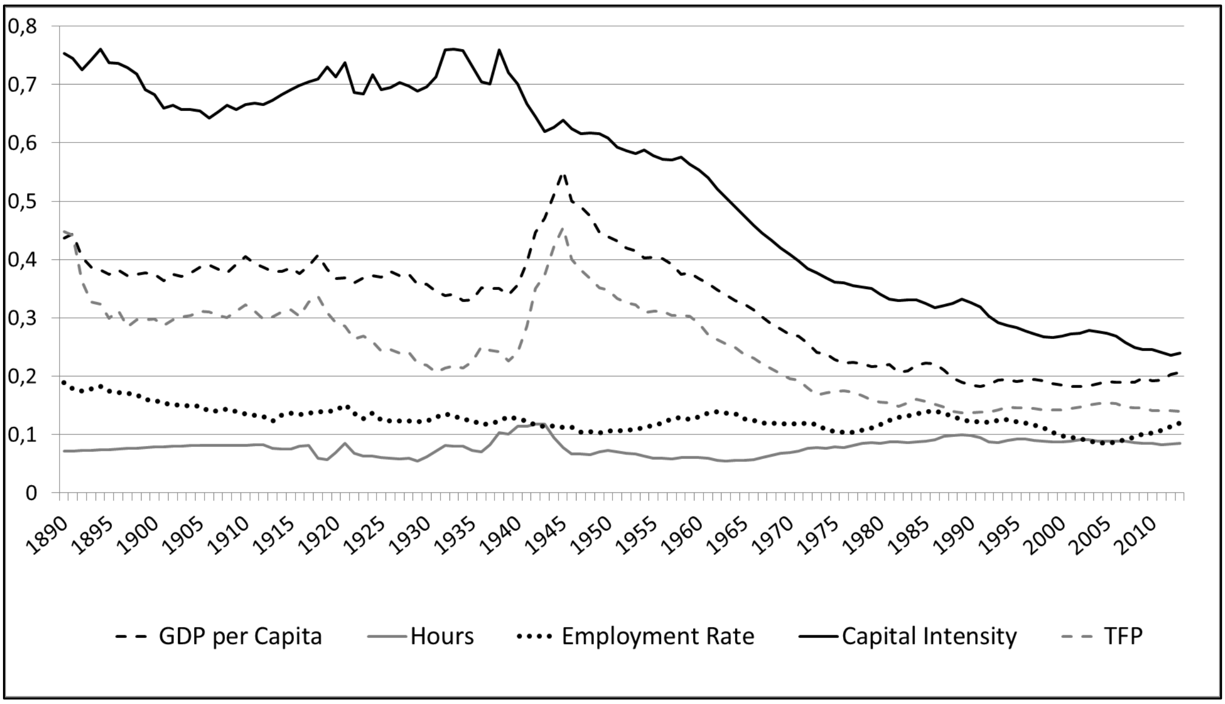
5. Convergence test: methodology, results and robustness

A first hint on the convergence process is given by the coefficients of variation (see chart 5), which normalize standard deviations by the mean.[11] For GDP per capita, the coefficient of variation is slowly decreasing from 1890 to WWII, jumps during WWII and is strongly decreasing until the 1990s. It has been stable since. This reflects an overall σ-convergence[12] over the whole period, brutally reversed during WWII and halted since the 1990s. This overall convergence relies on capital intensity, which coefficient of variation has strongly decreased since the end-1930s, and *TFP*, which coefficient of variation profile follows the one of GDP per capita. On the contrary, coefficients of variation for hours worked and the employment rate are almost flat (slightly decreasing for the employment rate), which reflects an absence of convergence for both indicators, but from a much lower dispersion level. We need to complement this first hint by looking at more formal tests, which we describe in 5.1, before presenting their results in 5.2 and various robustness tests and discussions in 5.3.

[11] To control for outliers and check for consistency, a similar graph is presented in appendix C, section C.3. This additional graph displays the normalized interquartile range for each series (see appendix for detail). The diagnosis offered by the Chart 5 appears robust.

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

Chart 5
Coefficients of variation (standard deviation / mean) for the 17 countries sample



5.1 The "*logt*" test of convergence

The five coefficients of variation presented in Chart 5 suggests a convergence dynamic for at least GDP per capita, capital intensity and *TFP* over the whole period. However, during some sub-periods, for example before 1950, this convergence process is less obvious. Does this steady evolution result from the fact that no convergence behavior is observed during this period or does it reflect the fact that countries cluster around different groups approaching a common steady state within each group? This question is crucial for our analysis and requires looking deeper into the convergence process. To do so, we rely on a methodology developed by Peter Phillips and Dongguy Sul, which relates to the family of σ-convergence tests.

Phillips and Sul (2007) (henceforth PS2007) have constructed a "*logt*" test of convergence based on a single regression. This test has the advantage of allowing for heterogeneity in the speed of convergence. We used this test and the algorithm described in Phillips and Sul (2009) to identify club convergence clusters for different time series and different subperiods.

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 component, the decomposition presented above allows 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* evolution at time *t*.

Unfortunately, it is in general impossible to estimate $\delta_{i,t}$ directly. For this reason, PS2007 introduce the relative transition coefficient $h_{i,t}$ constructed as the ratio of $\log x_{i,t}$ on the cross sectional mean of $\log x_{i,t}$:

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

Relative Transition coefficient $h_{i,t}$ measures the divergent behavior of a country *i* and its distance to a common steady state. When all countries converge, then $\forall i \in \{1,2,..,N\}, h_{i,t} \underset{t\to\infty}{\longrightarrow} 1$ and the modified cross sectional variance of *h*: $H_t = \frac{1}{N}\sum_{i=1}^{N}(h_{i,t}-1)^2 \underset{t\to\infty}{\longrightarrow} 0$.

With these results in mind, it is possible to derive a test of convergence. To do so, PS2007 assume that:

$$\delta_{i,t} = \delta_i + \frac{\sigma_i \xi_{i,t}}{t^{\alpha} \log t} \text{ for all i}$$[13]

Where δ_i is fixed, $\xi_{i,t}$ is *iid(0,1)* and σ_i is a positive parameter. This formulation shows that $\delta_{i,t}$ converges toward a common δ_i as long as $\alpha \geq 0$. The null hypothesis of convergence is therefore: H_0: $\delta_i = \delta$ for all i and $\alpha \geq 0$, against the alternative hypothesis: H_A: $\delta_i \neq \delta$ for some i or $\alpha < 0$.

Thus, the test of convergence can be boiled down to a test on the sign of α. PS2007 then show that this test is a Student test on the sign of the estimate of the coefficient β in the following equation:

$$\log\frac{H_1}{H_t} - 2\log\log t = a + \beta\log t + \varepsilon_t \text{ for t > rT}$$

In this equation, *r* is a coefficient ensuring 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 PS2007 for more details). The $2\, log\, log\, t$ acts as a commuting term: in the case of convergence, H_t is asymptotically equal to 0 so that $log\frac{H_1}{H_t}$ becomes very large. But in the case of divergence, H_t can take any value and the $2\, log\, log\, t$ ensures that the left hand side variable goes toward minus infinity. Finally, β is our coefficient of interest. Under the null hypothesis of convergence, $\beta \underset{P}{\Rightarrow} 2\alpha$ where α 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 statistics is lower than -1.65.

Following recommendations of PS2007 based on Monte-Carlo simulations, we set the coefficient *r* to 0.2. The regressions are based on OLS estimation with Newey West standard errors.

Based on this test, it is possible to know if there is any evidence of convergence in the sample, that is, if H_0 cannot be rejected. In that case, the value of β also gives insight about the speed of

[13] To be more accurate, the real assumption is that $\delta_{i,t} = \delta_i + \frac{\sigma_i \xi_{i,t}}{t^{\alpha}\mathrm{L(t)}}$ where L is a slowly varying function satisfying: $\frac{L(at)}{L(t)} \to 1$ as $t \to \infty$ for all $a > 0$ and $L(t) \to \infty$. The logarithm is a good candidate and it is the function which is recommended in PS2007 based on Monte Carlo simulations.

convergence.[14] However, if the null hypothesis is rejected, that is if there is neither absolute, nor conditional convergence, it is still possible to look at club convergence. PS2007 have constructed an algorithm to detect clusters of countries that gather into clubs, the description of which is in Appendix B. In next section, we run this algorithm to:

1. Detect any evidence of convergence according to the "*logt*" test (if the null hypothesis is not rejected),
2. Look at clubs of convergence if the null hypothesis is rejected.

5.2 Results

The tests presented in Table 1 confirm the hints from the coefficients of variations. Over the whole period, GDP per capita is converging at a moderate pace and this convergence relies on capital intensity and *TFP*, which are converging in level ($\beta > 2$) and particularly rapidly for capital intensity and labor productivity. Some convergence within different clubs occurs for hours worked and employment rates, but there are 4 clubs for hours worked and 2 for employment rates and the pace of convergence is slow within these clubs.

From 1895 to 1950, convergence in GDP per capita occurs only 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. As explained in section 4, this reversal hinges both on the US solitary "*One big wave*" and on the disruptions due to WWII as evidenced when looking at club 1 for both GDP per capita and labor productivity, where we can see that this group of leaders only contains countries that did not experienced the war on their soil. 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 clubs appears with a few countries left apart.

[14] In particular, if β is larger than 2, PS2007 argue that there is evidence of a convergence in level whereas if β is between 0 and 2, there is only evidence of convergence in growth 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 6 different variables on yearly data

When no country are indicated, this means that there is global convergence (the null hypothesis of convergence of the "logt" test cannot be rejected). The number into bracket is the estimated value of β (see previous section on the "*logt*" test methodology for details) either for the group or for the whole set of countries in case of global convergence. The larger β, 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 PS2007). 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). Countries list: Australia (AU), Belgium (BE), Canada (CA), Switzerland (CH), Germany (DE), Denmark (DK), Spain (ES), Finland (FI), France (FR), United Kingdom (GB), Italy (IT), Japan (JP), the Netherlands (NL), Norway (NO), Portugal (PT), Sweden (SE) and the United States (US).

	GDP per capita	Labor 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, CH, 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)

Table 2

Results when the Phillips-Sul Club Convergence test is used on the set of 17 countries in different sub-periods and for 6 different variables on quarterly data

See Table 1 for details.

	GDP per capita	Labor 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)*

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

Turning to tests on quarterly data in Table 2, we detect an overall GDP per capita convergence over the 1974-2013 period, but at a slower pace, relying on capital intensity and TFP. Employment rates are converging for all countries, but at a very slow rate. Indeed, since the 1990s, employment policies, as for example pension reforms, reversed in some European countries and led to an increase in employment rates until the Great Recession, whereas structural trends supporting the employment rate in the United States (women participation…) were exhausted, leading to an overall convergence. Two clubs appear for hours worked, with convergence on one side within the Germany, France, The Netherlands and Norway clubs towards low level and convergence for the rest of the sample on the other side towards higher level than the first club.

During 1974-1990, two GDP per capita convergence clubs appear, with most European countries on one side (characterized by average GDP per capita level and slowing growth) and other countries on the other. Spain and Portugal, with their low level of GDP per capita and fast growth, are not converging within any club. Over the period, no overall convergence is detected, while clubs and singletons are detected for other indicators. Two clubs appear for capital intensity, while the United Kingdom, Norway and Portugal are diverging. For TFP, three clubs are detected, which is a particularly disparate result, emphasizing 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). Employment rates and hours worked evolutions are particularly scattered, with 4 clubs and several singletons. The two GDP per capita clubs cannot be attributed to one specific indicator as the two clubs do not turn up in any of the clubs for the other indicators.

During 1990-2013, evolutions are particularly scattered with three clubs of slow convergence pace and Portugal diverging. No overall convergence appears for any other indicators, with two or three clubs of slow convergence and Norway diverging for labor productivity, capital intensity and employment rate. Indeed, the decade-long convergence process with the United States stopped in many countries: in continental European countries due to the limited diffusion of ICT relative to the United States; in Japan due to the banking crisis and subsequent deflation and in both due to high regulations and labor and product markets. On the contrary, some countries accelerated thanks to the structural reforms implemented in the aftermath of a crisis: Australia, Canada, Finland and Sweden. Finally, the Great Recession hit differently euro area countries and the rest of the world, with a less brutal but more protracted shock 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 on one side most weak *TFP*-growth countries (Canada, Spain, Italy, Japan, Portugal) and the others. Evolutions are more scattered for the other indicators.

Concerning the period 1974-2013, the overall global convergence detected for almost every series seems to hide a more complex transitional behavior. Indeed, when the time period is split into two subperiods (1974-1990 and 1990-2013), some clubs of convergence appear whereas a few countries (namely Portugal and Norway) diverge. Looking more closely at data for *TFP*, we can suspect that the global convergence is in fact the consequences of a merging between groups 1, 2 and 3 of the 1974-1990 periods into one group that appears in the next period (1990-2013). During this process, some countries have been left behind and cluster into a second club. These countries, Italy, Japan and Spain,[15] joined over the 1990-2013 period the convergence path of Portugal which was a diverging country before 1990. Thus, even if the "*logt"* 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 reorganization of these other countries into a common transitional path. This separation into two groups is too slow to be detected from the whole period scale (1974-2013) but is evidenced when focusing 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 low performances can receive different explanations: specialization in low-productivity sectors for Spain, high protective and anticompetitive regulations in agriculture and services for Japan, low relative education level for Portugal (7.9 years of schooling in average for the 15-64 population in 2010, while other countries show values ranging from 10.2 in Spain to 13.6 in the US), …

We now look at the sensitivity to our clubs with regards to some changes in a set of parameters. More detailed results are presented in appendix C.

5.3 Robustness and discussion about the club convergence detection

Before turning to the robustness and stability of the different convergence groups found above an important point about club convergence must be discussed. The methodology presented in PS2007 and the algorithm described in appendix B can only detect groups of countries that converge to the same steady state equilibrium. However, they tell nothing about the underlying factors that explain the existence of multiple *equilibria*. This question is important: if all 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 every characteristics but their initial conditions (they share comparable political system, population growth, technological level… but start from different level 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 Bartowska and Riedl (2012) a similar algorithm based on PS2007 is used to find club convergence among European regions. To give evidence in favor 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…) and a set of initial conditions (capital stock per capita, labor force…). They show that the probability of belonging to one group is sensitive to the initial conditions which confirms 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 on the other hand benefit from a very large time dimension which enables to change the initial date without loss of information.

[15] The presence of Canada is the group of laggards is not robust and less consistent with the series of labor productivity and GDP per capita. Canada is thus probably the reason of the weak coefficient associated with Club 2 in the period 1990-2013 for *TFP* and is not considered a laggard in the discussion.

To do so, we focus on GDP per capita and *TFP* and run the algorithm of club convergence detection after moving 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 give evidence against the club convergence hypothesis and suggest that initial level is not crucial in explaining the formation of these groups. On the contrary, if clubs are not stable, 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 decomposed into a very stable subgroup of leaders composed by Australia, Canada, Switzerland, Finland, Netherlands, Norway, Sweden and the US. These countries are allocated to the group 1 regardless 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 frontier of these clubs are 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 seen when using a longer time range.

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 subgroup of leaders, a transitional shock can change their transitional path. In this case, they can join the group of leaders, for UK, or diverge as for Portugal. For *TFP*, the conclusions are different. Because initial conditions do not seem to matter for the formation of the groups, then a transitory shock may not affect a country transitional path. Consequently, countries that are considered as laggard in terms of TFP, *ie* Japan, Spain, Italy and Portugal, are stuck in a convergence path into a different steady state than other countries.

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

See Table 1 for details.

GDP per capita		
1987 - 2013	**1990 - 2013**	**1993 - 2013**
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		
1987 - 2013	**1990 - 2013**	**1993 - 2013**
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

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 PS2007 algorithm. First, we look at the assumption made for the construction of our series. In particular, we set the value of α, 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 relax these assumption by allowing α to be equal to 0.25 (low value) and 0.35 (high value) and separately the depreciation rate to be set 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 look at specific assumption made in the algorithm itself and concerning the initial order of countries and the value of the trimming coefficient r (see appendix B for a description of the algorithm).

In every case, results are not strongly affected by these changes. In particular global convergences results are always robust.

6. Conclusions

Long term views on GDP per capita are useful to characterize long developments about convergence processes in standards of living and country economic development. In this study, we built a database over 1890-2013 for seventeen advanced countries: the ones in the G7 (the United States, Japan, Germany, France, the United Kingdom, Italy and Canada), the other three biggest countries of the Euro Area (Spain, the Netherlands and Belgium), two other countries of this Area (Portugal and Finland) and five other OECD countries interesting for productivity analysis because of some specificities, such as a high productivity level at the beginning of the period for Australia, a particular industry structure for Norway and Switzerland and the role of structural policies for Sweden and Denmark. In addition, a Euro Area has been reconstituted, aggregating Germany, France, Italy, Spain, the Netherlands, Belgium, Portugal and Finland.

The study presents a GDP per capita level and growth comparison 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 total factor productivity, capital intensity, working time and employment rate. Convergence tests are also proposed on GDP per capita and its components over different sub-periods. The test methodology is inspired by Phillips and Sul (2007), this methodology being related to the family of σ-convergence tests.

The main results are the following: i) All countries experienced at least one big wave of GDP per capita growth during the 20th Century, but in a staggered manner. The size of the wave seems related to the starting level: it was the strongest in Japan and the lowest in the United Kingdom, the Euro Area being in an intermediate position; ii) Almost all countries have suffered, during the last decades of the period, from a huge decline in GDP per capita growth; iii) The GDP per capita leadership changed over the period: the UK was the leader until WWI and for some years during the Great Depression, but US has maintained its leadership since WWII; iv) There is an overall convergence process among advanced countries, mainly after the WWII, first through capital intensity and then *TFP*, while evolutions in hours worked and even more employment rates are more disparate; v) But this convergence process is not continuous. It was particularly scattered since 1990, as the convergence of the EA, the UK and Japan to the US GDP per capita level stopped at a large distance from the US level, with reforming or structurally flexible countries accelerating thanks to ICT, while some countries such as Japan lingered in crisis. This fact means that the GDP per capita catch-up to the leadership position is not always ongoing; vi) Other club convergence processes appear during some subperiods, mainly on post WWII decades. Employment rate and hours worked are mainly concerned, with continental European countries characterised by lower levels than Anglo-Saxon countries for these variables.

Policies may influence the relative GDP per capita levels. Apart from policies supporting innovations, the most relevant ones to influence the convergence process of GDP per capita are the ones which allow the faster productivity benefit from technological shocks, and for example policies reducing anticompetitive barriers on the product market, or introducing more flexibility on the labor market, and of course policies increasing the education level of the working age population (see on these aspects Aghion and Howitt, 1998, 2006, 2009, and Aghion *et al*. 2009 for an empirical illustration). But they are also policies impacting labor supply. On this last aspect, compared to the US, the GDP per capita in the EA suffers in the last decades from lower employment rates. The increase of the participation rate in the EA over the two last decades illustrates the large role of policies.

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Appendices

Appendix A
Data Construction and Sources

This appendix presents the sources and the construction of the dataset used in this study. The dataset builds on Bergeaud *et al.* (2014) where macroeconomics series for 13 countries were compiled over the period 1890-2012. We completed this dataset in two ways. First, we added four European countries to the dataset: Belgium, Denmark, Portugal and Switzerland, for a total of 17 OECD members. Second, we extended the time series to 2013 and integrated the new accountings methodologies (ESA2010 in Europe and SNA08 all around the world) which involve major changes in both GDP and Investment series[16] namely by capitalizing Research and Development expenditures (that is: R&D expenditures are now considered as a fixed asset). In our set of 17 countries, Japan is the only which did not present complete updated series by the end of 2014.[17] For this county, we made adjustments which are described in the appropriate sections below. For other countries, the new SNA or ESA national account series have been completed.

All in all, our dataset covers the period 1890-2013 (and most of the time, data are available from a prior date) for 17 OECD countries (Australia (AUS), Belgium (BEL), Canada (CAN), Switzerland (CHE), Germany (DEU), Denmark (DNK), Spain (ESP), Finland (FIN), France (FRA), United Kingdom (GBR), Italy (ITA), Japan (JPN),The Netherlands (NLD), Norway (NOR), Portugal (PRT), Sweden (SWE), United States (USA)). In addition, a reconstituted Euro Area is constructed which is here the aggregation of Germany, France, Italy, Spain, the Netherlands, Belgium, Portugal and Finland. This approximation seems acceptable as these six countries represent together, in 2010, 91% of the total current GDP of the Euro Area. Each of the 17 countries is considered in its borders of 2013.[18]

To construct series for GDP per capita, Total Factor Productivity (*TFP*), capital Intensity, hours worked and employment per capita which are used in this article, we needed to compute data concerning GDP (Y), population (P), total hours worked ($L = N \cdot H$), employment (N), average working time (H), capital (K). Capital calculation needs itself long information concerning investment (I).

Finally, the series of GDP and investment are given in volume and converted in US dollars in purchasing power parity of 2010 using conversion rates from the Penn World Table Heston *et al.* (2011).

<u>Gross Domestic Product</u> (*Y*)

Australia: 1820-1960: Bolt et al. (2013) updating Maddison (2001). 1960-2013: Australian National Accounts (ABS).
Belgium: 1846-1980: Bolt et al. (2013) updating Maddison (2001). 1980-2013: Eurostat National Accounts.
Canada: 1870-1981: Bolt et al. (2013) updating Maddison (2001). 1981-2013: Canadian National Accounts (STATCAN)
Denmark: 1820-1966: Bolt et al. (2013) updating Maddison (2001). 1966-2013: Eurostat National Accounts.
Finland: 1860-1960: Bolt et al. (2013) updating Maddison (2001). 1960-1975: National Accounts of Finland (Tilastokeskus). 1975-2013: Eurostat National Accounts.
France: 1820-1949: Bolt et al. (2013) updating Maddison (2001). 1949-2013: Eurostat National Accounts.
Germany: 1850-1970: Bolt et al. (2013) updating Maddison (2001). 1970-1991: German National Accounts (Destatis). 1991-2013: Eurostat National Accounts.
Italy: 1861-1990: Baffigi (2011). 1990-2013: Eurostat National Accounts.
Japan: 1870-1970: Bolt et al. (2013) updating Maddison (2001). 1970-1996: OECD National Accounts. 1996-2013: Based on OECD National Accounts series of GDP to which we added R&D expenditures from the OECD

[16] But also for population and employment as most National Statistic Offices used the opportunity of a global update to re-examine their classifications and make some readjustments. However, these changes are very negligible as compared to changes in GDP and Investment.
[17] Japan planned to integrate the SNA08 in 2016.
[18] This is even true if the country does not exist in a subperiod of 1890-2013. For example, we considered current boarder of Finland even before 1917 when Finland was a region of the Russian Empire.

data. To check consistency, we calculated the correlation between R&D expenditures in US$ 2010 ppp and the increase of GDP due to the change of methodology for every other country and derived a correcting factor taken into accounts other potential changes in GDP series.
Netherlands: 1820-1969: Bolt et al. (2013) updating Maddison (2001). 1969-2013: Eurostat National Accounts.
Norway: 1830-1970: Bolt et al. (2013) updating Maddison (2001). 1970-1995: Norwegian National Accounts (SSB). 1995-2013: Eurostat National Accounts.
Portugal: 1865-1995: Bolt et al. (2013) updating Maddison (2001). 1995-2013: Eurostat National Accounts.
Spain: 1850-1980: Bolt et al. (2013) updating Maddison (2001). 1980-2013: Eurostat National Accounts.
Sweden: 1800-1820: Swedish Historical National Account (1800-2000). 1820-1950: Bolt et al. (2013) updating Maddison (2001). 1950-2013: Eurostat National Accounts.
Switzerland: 1850-1980: Bolt et al. (2013) updating Maddison (2001). 1980-2013: Swiss National Accounts.
United Kingdom: 1820-1949: Bolt et al. (2013) updating Maddison (2001). 1949-2013: Eurostat National Accounts.
United States: 1870-1929: Bolt et al. (2013) updating Maddison (2001). 1929-1970: Bureau of Economic Analysis: GDP and Other Major NIPA series 1929-2011. 1970-2013: Eurostat National Accounts.

Total Population (***P***)

Australia: 1820-1960: Bolt et al. (2013) updating Maddison (2001). 1960-2013: World Development Indicator (WDI) of the World Bank.
Belgium: 1820-1960: Bolt et al. (2013) updating Maddison (2001). 1960-1995: WDI. 1995-2013: Eurostat National Accounts.
Canada: 1870-1960: Bolt et al. (2013) updating Maddison (2001). 1960-2013: WDI.
Denmark: 1820-1960: Bolt et al. (2013) updating Maddison (2001). 1960-1995: WDI. 1995-2013: Eurostat National Accounts.
Finland: 1820-1960: Bolt et al. (2013) updating Maddison (2001). 1960-1980: WDI. 1980-2013: Eurostat National Accounts.
France: 1820-1960: Bolt et al. (2013) updating Maddison (2001). 1960-1975: WDI. 1975-2013: Eurostat National Accounts.
Germany: 1850-1960: Bolt et al. (2013) updating Maddison (2001). 1960-1991: WDI. 1991-2013: Eurostat National Accounts.
Italy: 1870-1960: Bolt et al. (2013) updating Maddison (2001). 1960-1995: WDI. 1995-2013: Eurostat National Accounts.
Japan: 1870-1960: Bolt et al. (2013) updating Maddison (2001). 1960-1970: WDI. 1970-2013: Eurostat National Accounts.
Netherlands: 1820-1960: Bolt et al. (2013) updating Maddison (2001). 1960-1995: WDI. 1995-2013: Eurostat National Accounts.
Norway: 1820-1960: Bolt et al. (2013) updating Maddison (2001). 1960-2013: WDI.
Portugal: 1820-1960: Bolt et al. (2013) updating Maddison (2001). 1960-1995: WDI. 1995-2013: Eurostat National Accounts.
Spain: 1850-1960: Bolt et al. (2013) updating Maddison (2001). 1960-1995: WDI. 1995-2013: Eurostat National Accounts.
Sweden: 1820-1960: Bolt et al. (2013) updating Maddison (2001). 1960-1995: WDI. 1995-2013: Eurostat National Accounts.
Switzerland: 1820-1960: Bolt et al. (2013) updating Maddison (2001). 1960-2013: WDI.
United Kingdom: 1830-1960: Bolt et al. (2013) updating Maddison (2001). 1960-1995: WDI. 1995-2013: Eurostat National Accounts.
United States: 1870-1960: Bolt et al. (2013) updating Maddison (2001). 1960-1975: WDI. 1975-2013: Eurostat National Accounts.

Total Employment (***N***)

Note: Data referred to as CB-TED come from *The Conference Board Total Economy Database*.

Australia: 1890-1901: Maddison (2001) and variation of total population are used to estimate the value of employment from 1890. 1901-1950: Butlin (1977). 1950-1985: CB-TED. 1985-2013: OECD National Accounts.
Belgium: 1846-1913: Mitchell (1998b), linearly interpolated between years (1846, 1856, 1866, 1880, 1890, 1900, 1910, 1920). 1913-1950: Clark (1957). 1950-1995: CB-TED. 1995-2013: Eurostat National Accounts.
Canada: 1871-1960: Historical Statistics of Canada (section D) (prior to 1921, data are given every 10 years and have been interpolated). 1950-1970: CB-TED. 1970-2013: OECD National Accounts.
Denmark: 1870-1950: Hansen (1974). 1950-1995: CB-TED 1995-2013: Eurostat National Accounts.
Finland: 1860-1950: Hjerppe (1996). 1950-1980: CB-TED. 1980-2013: Eurostat National Accounts.
France: 1890-1950: Villa (2004). 1950-1975: CB-TED. 1975-2013: Eurostat National Accounts.
Germany 1852-1939 (except 1913-1924): Hoffman (1965); 1913 to 1924: we used figures of unemployment over total population, computed by Mitchell (1998b); 1939-1950: we have computed these data through a sixth-degree polynomial interpolation; 1950-1991: CB-TED.1991-2013: Eurostat National Accounts.
Italy: 1861-1950: Broadberry *et al.* (2011). 1950-1995: CB-TED. 1995-2013: Eurostat National Accounts.
Japan: 1870-1885: Maddison (2001) interpolated between 1870 and 1913. 1885-1950: Liesner (1989). 1950-1960: CB-TED. 1960-2013: National Accounts.
Netherlands: 1800-1913: Smits *et al.* (2000). 1913-1950: Van Ark and De Jong (1996). 1950-1995: CB-TED. 1995-2013: Eurostat National Accounts.
Norway: 1865-1900: Mitchell (1998b) interpolated between 1865, 1891 and 1900). 1900-1950: Historical Statistics of Norway. 1950-1970: CB-TED. 1970-2013: OECD National Accounts.
Portugal: 1890-1950: Valerio (2001) interpolated using variation of working age population. 1950-1995: CB-TED. 1995-2013: Eurostat National Accounts.
Spain: 1850-1950: Prados (2003). 1950-1995: CB-TED. 1995-2013: Eurostat National Accounts.
Sweden: 1850-1950: *Swedish Historical National Account 1800-2000*. 1950-1995: CB-TED. 1995-2013: Eurostat National Accounts.
Switzerland: 1870-1890: Mitchell (1998b) linearly interpolated between 1870, 1880, 1888, 1900. 1890-1950: Clark (1957). 1950-1991: CB-TED. 1991-2013: OECD National Accounts.
United Kingdom: 1855-1920: Feinstein *et al.* (1988). 1920-1950: Office for National Statistics. 1950-1980: CB-TED. 1980-2013: OECD National Accounts.
United States: 1850-1890: Clark (1957) linearly interpolated between 1850, 1860, 1869 and every 5 years until 1894. 1890-1950: Mitchell (1998a). 1950-1970: CB-TED. 1970-2013: OECD National Accounts.

Average hours worked per year (*H*)

Note: Data referred to as "Huberman and Minns (2007) + Clark (1957)" are built according to Huberman and Minns (2007) benchmark estimates (1870, 1880, 1890, 1900, 1913, 1929, 1938 and 1950) and Clark profile.[19] Data only referred to as "Huberman and Minns (2007)" are linear interpolation of Huberman and Minns data.

The same methodology is used for every country except Finland, Norway, Japan and Portugal for which we use Maddison (2001) estimates.

Australia: 1870-1913: Huberman and Minns (2007). 1913-1950: Huberman and Minns (2007) + Clark (1957). 1950-1978: CB-TED. 1978-2013: OECD National Accounts.
Belgium: 1870-1895: Huberman and Minns (2007). 1895-1950: Huberman and Minns (2007) + Clark (1957). 1950-1970: CB-TED. 1970-2013: OECD National Accounts.
Canada: 1870-1913: Huberman and Minns (2007). 1913-1950: Huberman and Minns (2007) + Clark (1957). 1950-1961: CB-TED. 1961-2013: OECD National Accounts.
Denmark: 1870-1950: Huberman and Minns (2007) + Clark (1957). 1950-1967: CB-TED. 1967-2013: OECD National Accounts.
Finland: 1870-1913: Maddison (2001). 1913-1950: Maddison (2001) + Clark (1957). 1950-1960: CB-TED. 1960-2013: OECD National Accounts.
France: 1870-1950: Huberman and Minns (2007) + Clark (1957). 1950-2013: OECD National Accounts.
Germany: 1870-1950: Huberman and Minns (2007) + Clark (1957). 1950-1976: CB-TED. 1976-2013: OECD National Accounts.

[19] More precisely, we have chosen to use the values of total hours worked from Huberman and Minns (2007) and to use the growth rate of Clark which we weighted in order to fit Huberman and Minns estimates.

Italy: 1870-1901: Huberman and Minns (2007). 1901-1950: Huberman and Minns (2007) + Clark (1957). 1950-1980: CB-TED. 1980-2013: OECD National Accounts.
Japan: 1870-1913: Maddison (2001). 1913-1950: Maddison (2001) + Clark (1957). 1950-1970: CB-TED. 1970-2013: OECD National Accounts.
Netherlands: 1870-1913: Huberman and Minns (2007). 1913-1994: Van Ark and De Jong (1996). 1994-2013 OECD National Accounts.
Norway: 1870-1913: Maddison (2001). 1913-1950: Maddison (2001) + Clark (1957). 1950-1962: CB-TED. 1962-2013: OECD National Accounts.
Portugal: 1870-1950: Assumed to Maddison benchmark for Spain, linearly interpolated. 1950-1986: CB-TED. 1986-2013: OECD National Accounts.
Spain: 1870-1977: Prados et al. (2010). 1977-2013: OECD National Accounts.
Sweden: 1870-1950: Huberman and Minns (2007) + Clark (1957). Between 1939 and 1942, average weekly hours worked from Liesner (1989) are used to interpolate. 1950-2013: OECD National Accounts.
Switzerland: 1870-1890: Huberman and Minns (2007). 1890-1950: Huberman and Minns (2007) + Clark (1957). 1950-1991: CB-TED 1991-2013: OECD National Accounts.
United Kingdom: 1870-1950: Huberman and Minns (2007) + Clark (1957). 1950-1970: CB-TED. 1970-2013: OECD National Accounts.
United States: 1870-1950: Huberman and Minns (2007) + Clark (1957). 1950-2013: OECD National Accounts.

Gross Fixed Capital Formation (*I*)

We divided total gross fixed capital formation between two types of assets. First we considered buildings investment, including dwellings, then we considered investment in machineries and equipments. The purpose of this separation is to apply different depreciation rates. Unless otherwise stated, building and equipment investment series cover the same period.

Australia: 1880-1902: Both types of investments are supposed to follow total investment from Mitchell (1998c). 1902-1960: Butlin (1977). 1960-2013: Data from Australian National Accounts (ABS)**.**
Belgium: 1890-1900: Investment in buildings is supposed to follow investment in dwellings from Buyst (1992). Investment in machinery and equipment in supposed to follow the growth of GDP. 1900-1986: Van Meerten (2003). 1986-1995: Bank of Belgium. 1995-2013: Eurostat National Accounts.
Canada: 1871-1900: Historical Canadian Macroeconomic Dataset (1871-1994), from which we use total investment in value, deflated using Implicit Price Deflator. 1900-1926: Historical Statistics of Canada (Section F), where data are only given every five years. We spread these data following the growth of total investment. 1926-1975: Historical Statistics of Canada (Section F). 1975-2013: Canadian National Accounts.
Denmark: 1875-1966: Hansen (1974). 1966-2013: Eurostat National Accounts.
Finland: 1860-1960: Hjerppe (1989). 1960-1975: National Accounts of Finland. 1975-2013: Eurostat National Accounts.
France: 1820-1935: Levy-Leboyer (1978). Total GFCF has been split according to Villa (1994). 1935-1949: Maddison (1994). 1949-1978: INSEE. 1978-2013: Eurostat National Accounts.
Germany: Investment in Buildings: 1850-1880: Kirner (1968). 1880-1970: Maddison 1994. 1970-1991: OECD National Accounts. 1991-2013: Eurostat National Accounts.
Investment in Machinery and Equipment: 1850-1870: we supposed that equipment investment trend was the same as the one of building investment. 1870-1920: Kirner (1968), we assumed that total equipment trend follows investment in equipment in the sector "Schifffahrt" (Navigation and Shipping). 1920-1970: Maddison (1994). 1970-1991: OECD National Accounts. 1991-2013: Eurostat National Accounts.
Italy: 1861-1991: Baffigi (2011). 1991-2013: Eurostat National Accounts.
Japan: 1870-1980: Maddison (1994). 1980-2013: OECD National Accounts. From 1996, the same transformation as in GDB has been made to account for R&D.
Netherlands: 1800-1880: Smits *et al.* (2000). 1880-1969: Groote *et al.* (1996). 1969-2013: Eurostat National Accounts.
Norway: 1865-1900: Statistisk Sentralbyra (SSB) Historical National Accounts. After 1900, eight points are given (1910, 1920, 1930, 1939, 1946, 1950, 1955 and 1960). We used those data to calculate the weight of equipment over total investment and interpolated this ratio. 1900-1949: Grytten (2004) data of total investment separated with SSB ratio. 1949-1972: SSB Historical Statistics.1972-1995: National Accounts of Norway. For all those data, we chose to consider ships and oil platforms as buildings. 1995-2013: Eurostat

National Accounts.
Portugal: 1890-1911: Variations in GDP are used to backdate both types of investment. 1911-1953: Lains and Da Silva (2013). 1953-1995: Bank of Portugal. 1995-2013: Eurostat National Accounts.
Spain: 1850-1980: Prados (2003). 1980-2013: Eurostat National Accounts
Sweden: 1800-1980: Swedish Historical National Accounts 1800-2000. 1980-2013: Eurostat National Accounts.
Switzerland: 1852-1948: Ritzmann-Blickensorfer (1996). 1948-2013: Swiss National Accounts.
United Kingdom: 1800-1948: Maddison (1994). 1948-1980: National Accounts of the UK. 1980-2013: Eurostat National Accounts.
United States: 1870-1970: Maddison (1994). 1970-1999: OECD National Accounts. 1999-2013: Bureau of Economic Analysis.

Capital (*K*)

Calculation

The perpetual inventory method (PIM) is used to construct the capital series from data on investment. Equipment and building investment (*IE* and *IB*) and capital (*KE* and *KB*) are distinguished with different life expectancy. The annual depreciation rates, denoted δ, have been chosen according to Cette *et al.* (2009) as 10% for equipment and 2.5% for buildings. In addition, for each year, we updated the given capital stock with a war and natural disasters damage coefficient (d_t) (with $0 \leq d_t \leq 1$) in order to take into consideration the capital destruction.

The PIM corresponds to the relation $K_{t+1} = \left(K_t * (1-\delta) + I_{t+1} * \sqrt{1-\delta}\,\right) * \,(1 - d_{t+1})$. This relation assumes that the whole investment is done in one flow and in the middle of the year which explains that a part of it is slightly depreciated with a coefficient $\sqrt{1-\delta}$ at the end of the year.

Initialization

In order to calculate K_t for every year, we need to initialize the capital stock at t_0. To do so, we considered that the growth of capital follows the average growth of GDP. We calculated the average growth rate for the first ten available data of our study for each country. Let g be this growth (initial war and natural disasters damage coefficient is assumed to be null): $g = \frac{K_{t_0+1} - K_{t_0}}{K_{t_0}} = -\delta + \sqrt{(1-\delta)}\frac{I_{t_0+1}}{K_{t_0}}$ or equivalently: $K_{t_0} = \frac{\sqrt{(1-\delta)}}{\delta + g} I_{t_0+1}$.

The initialization date t_0 varies among countries and depends of the shortest time series between investment and GDP, see Table A1 below.

Table A1

Initialization date (t_0) of the capital series (*K*)

Australia	1880	**Netherlands**	1821
Belgium	1890	**Norway**	1865
Canada	1871	**Portugal**	1890
Denmark	1875	**Spain**	1851
Finland	1861	**Sweden**	1801
France	1821	**Switzerland**	1852
Germany	1850	**United Kingdom**	1831
Italy	1862	**United States**	1875
Japan	1885		

War and major natural disasters damage

Australia: None.
Belgium: Following (Madsen, 2010) who exploits information given in (Van Meerten, 2003), we supposed a 15.5% of 1913 GDP destruction of capital during world war one evenly spread between 1914 and 1918 and a 7.1% of capital destruction evenly spread between 1943 and 1945.
Canada: None.
Denmark: None.
Finland: None.
France: Villa (1994). Villa uses a different approach by changing the depreciation rate according to destruction laws. We had to convert them in order to fit with our model.
Germany: According to Demotes-Mainard (1989), West Germany underwent a loss of 15% in capital during WW2. Among them, 3% is a consequence of factory disassembling in 1945. In order to spread the remaining 12%, we used the information from Humble (1975) concerning bombs dropped by the Allies over the German territory (Table A2).

Table A2

Bombing over Germany by Royal Air Force and US Air Force
Source: Humble (1975)

Year	RAF bombing (in tons)	USAF bombing (in tons)	% of total	Among the 12% loss without disassembling
1939	31	0	0	0
1940	13,033	0	0.82	0.10
1941	31,504	0	1.98	0.24
1942	45,561	1,561	2.97	0.36
1943	157,457	44,165	12.70	1.52
1944	525,518	389,119	57.59	6.91
1945	191,540	188,573	23.94	2.87

Italy: Following Broadberry *et al.* (2011), we assumed 1% of war damage in both equipment and building capital in 1944 and another 1% in 1945.
Japan: For damages caused by major natural disasters, we used a study by the OECD *From tragedy to the revitalization of Japan, OECD Economic survey, Japan 2013*. For WW2, we used a document kindly provided by the Bank of Japan and entitled *Hundred Years Statistics of the Japanese Economy.*
Netherlands: Following Madsen (2010), we assumed 3.5% war damage between 1943 and 1945.
Norway: None.
Portugal: None.
Spain: According to Prados *et al.* (2008), total capital destruction in Spain during the civil war reached 7% of the 1935 capital stock. Besides, buildings and infrastructures were destroyed by 4% to 6%. We deduced the capital destruction in equipment and spread the damages between 1936 and 1938.
Sweden: None.
Switzerland: None.
United Kingdom: Following Madsen (2010), we added 3.3% war damage between 1943 and 1945.
United States: None.

<u>Quarterly series</u>

We used OECD quarterly national accounts and economic outlook data to construct quarterly series from 1974 to 2013 based on annual benchmarks. According to the kind of data (stock or flow) our methodology differs.

Flow data (GDP, Investment)

For flow data, quarterly data have been used and scaled such that the sum of the four quarters is equal to the annual data. To formalize this, let X_t be the value of a given series (say, GDP) at the end of year t and let $X_{t,q}$ the value of the same series at the end of each quarter. Then, we want our final series Y to verify: $X_t = \sum_{i=0}^{4} Y_{t,i}$. The easiest way to achieve this is to use:

$$Y_{t,q} = \frac{X_t}{\sum_{i=0}^{4} X_{t,i}} X_{t,q}$$

Stock data (Employment, Hours)

For stock data, the idea is the same but now the condition is that the observation for the last quarter be equal to our annual estimate. Formally, using the same notations as above: $Y_{t,4} = X_t$. Once again, we scale the quarterly data in order to meet this condition:

$$Y_{t,q} = \frac{X_t}{X_{t,4}} X_{t,q}$$

Capital Stock data

We proceed as for annual data considering a depreciation rate δ_q, such that $(1 - \delta_q) = (1 - \delta)^{1/4}$. We didn't consider any war and natural disaster damage for quarterly data, except for Japan in 1995 and 2011. In order to initialize the series of capital, we use the value of capital at the end of 1959 given by annual data.

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Appendix B
Detection of Convergence Club

The algorithm used to detect convergence clubs has been implemented in Stata.

Notations: Let *N* be the total number of countries (*N = 17*), T the size of the time dimension (for example, between 1950 and 2013, *T = 64*) and *c* is the threshold used for the t-statistics for Step 3. Data have been filtered by a HP filter with a lambda coefficient of 6 to remove the smallest fluctuations.

Step 0: Before looking at potential convergence clubs, we check if there is global convergence. For this, we run the *logt* test for the set of *N* countries. If the resulting t-statistics is above -1.65, then we conclude that there is global convergence, that is every country converges to the same steady state. Otherwise, we proceed to Step 1.

Step 1: Ordering countries according to the value of the last 5 observations. Because for some subperiods, the order can be very volatile, we took the average of the last 5 observations to order countries. In addition, because we focus on comparisons with the US, we chose to automatically set this country's order to 1.[20]

Step 2: Identification of the Core Group. We start with the first k ($2 \leq k < N$) countries according to the ordering in the previous step. Then we run the *logt* test for this group of size k, store the t-statistics t_k and select the optimal value of k, denoted k* such that: $k^* = argmax_{2\leq k<N}\,(t_k)$ *subject to* $t_k > -1.65$.If $t_2 < -1.65$ then we remove the first country from the group of country of size *k* and then we run Step 2 again starting with country number 2. The resulting group of size *k** is our Core Group. If the condition $t_2 > -1.65$ never holds, then we conclude that there is no evidence of club convergence for the group of countries.

Step 3: We continue by adding countries one at a time to the Core Group and run the *logt* test for this new group. If the new t-statistics is above a threshold c, then this country is included in the Core Group. The resulting group is denoted the first subconvergence group. We run the *logt* test for this subconvergence group, if the t-statistics t is higher than -1.65, then we keep this group, otherwise we increase the value of c and start again Step 3 with the Core Group found after Step 2 until the t-statistics is above -1.65.

Step 4: For the set of countries that do not belong to the first subconvergence group, we run the *logt* test. If the resulting t-statistics is above -1.65, then we have found our second subconvergence group[21] and the algorithm ends.[22] Otherwise, we start over at Step 1 with this new set of countries.

Step 5: Merging clubs. When reaching Step 5, we are left with p clubs, each of them containing n(i) members $2 \leq i \leq p$ and a number s of countries that do not belong to any of these clubs (so that $s + \sum_{i=1}^{p} n(i) = N$). Starting with the first club, we take every country from this club and from the following one and run the *logt* test. If the resulting t-statistics is over -1.65, then we merge these two clubs and we proceed again by looking at evidence of merging between this new club and the next one and so on until the convergence hypothesis is rejected. Then move to the last group that did not merge with the previous one and run Step 5 again.

[20] That is US is always added to the Core Group (see step 2). According to Phillips and Sul (2009) the order of the countries has little impact on the final clubs clusters. We removed this arbitrary change of order as a robustness check.

[21] It is therefore possible for a club to be associated with a t-statistics between -1.65 and 1.65. In this case, convergence within this club cannot be rejected but the coefficient of the logt test is no longer the speed of convergence.

[22] If there is only one country outside the first subconvergence group, then we conclude that this country does not belong to any club and the algorithm ends.

Appendix C
Robustness

In this appendix, we discuss some robustness control, especially regarding the detection of club convergence. There are indeed parameters that can be tested, entering either in the construction of the series (namely the coefficient of the Cobb-Douglas production function α and the depreciation rates δ_B, for building and δ_M for equipment) or in the algorithm used to gather countries in different groups (the coefficient r and the order of countries).

C.1. **Changes in the series**

In this section, we will look at the modifications in convergence results when the parameters used in the construction of the time series are set to an upper and lower bond level.

Coefficient	Original Value	High Value	Low Value	Series Affected
α	0.3	0.35	0.25	TFP
$\boldsymbol{\delta_B}$	0.025 40 years	0.050 20 years	0.015 67 years	TFP, Capital Intensity
$\boldsymbol{\delta_M}$	0.10 10 years	0.15 6.7 years	0.05 20 years	TFP, Capital Intensity

With the updated series, we run the algorithm of club convergence detection again (see table C1, and table C2). The only series that are affected by these changes are capital intensity and *TFP*. In each table, we display the results when each parameter is (separately) set to its high value and its low value in addition to the results of tables 1 and 2 as a reminder.

From tables C1 and C2, we can see that results are rather stable. In table C1, there are only minor modifications on the speed of (global) convergence for capital intensity and for *TFP*, but every results for global convergence hold. In table C2, when quarterly data are used, more changes appear. Starting with capital intensity, we can see that changing the value of δ does not affect the global convergence during the period 1974-2013 (the speed of convergence is also very stable). Between 1974 and 1990, Australia, Canada and Italy are moving from group 2 to group 1 while the UK, Norway and Portugal are still on a no converging path (except when the high value of δ is used, in this case the UK and Finland are grouped together). Similar observations can be made for the period 1990 – 2013 in which Norway is still on a no converging path while some minor adjustments are made between group 1 and group 2 and group 2 and group 3. Interestingly, when the low value of δ is used, groups 2 and 3 are merged into a unique group (with the exception of Germany and Denmark which moved to group 1). When looking at results for *TFP*, we can see that between 1974 and 2013, the global convergence is very stable, showing consistent speed of convergence. For the period 1974-1990, global convergence, associated with a t stats below 1.65 is observed when δ is set to its high or low value. When α is set to a high value, this global convergence appears again but this time with a very small but significant speed of convergence. Finally, when α is set to its low value, two groups can be seen, the first one is very similar to the case where α is equal to 0.3 and the second one has absorbed Sweden and Canada. Portugal is now left alone. Finally, for the period 1990-2013, results are very consistent and always lead to two groups, with the second group being composed of productivity laggards: Japan, Portugal, Spain and Italia. Two exceptions appear. First Canada which either belongs to the second group, to the first group or to no convergence group, suggesting that this country is responsible for the small value of the t-statistics for group 2 in table 2. Second, Switzerland which no longer converge when a high value of α is used.

Considering the significant changes made to the series,[23] the results observed in tables C1 and C2 suggest a good robustness and stability of the clubs with respect to the assumption made for the construction of capital and *TFP*.

[23] As an example, in 2013 for the US *TFP*, moving from the low to the high value of α involve a multiplication by a factor 1.7.

C.2 **Changes in the algorithm**

With respect to the original algorithm as described by Phillips and Sul (2007), two parameters values have to be chosen. First the trimming coefficient *r*, ensuring that a percentage of the first observations are not taken into account in the regressions can be set to any number between 0.2 and 0.3 according to Monte Carlo tests. Second the ordering of the countries in the first step of the algorithm (see appendix B) can be made according to the last observation as suggested by Phillips and Sul or by any other way since it does not theoretically change anything. Because in a large part of this article, we compare OECD countries with the USA, we have decided to automatically set the order of the USA to 1 while other countries are ordered according to their last observation.[24]

In order to test that the first point described above does not change our results, we run the algorithm again setting the trimming coefficient *r* to 0.3.[25] For annual data, series for labor productivity, capital intensity and TFP are perfectly consistent. Minor changes appear in series of hours worked and employment rate. Thus, between 1895 and 1950, Spain is integrated to the group 2 for employment rate and group 2 and group 3 merge for hours worked. Between 1950 and 2013, Portugal and the USA switch from group 1 to group 2 for employment rate and group 2 composed of France and Belgium disappears for hours worked series (France joins group 3 while Belgium joins group 1), in addition, non-converging countries (Norway, Switzerland and the UK) are affected to the new group 1. Finally, for GDP per capita, the only change involved by the modification of *r* is observed between 1895 and 1950 with groups 2, 3 and 4 merging into two groups, the first one composed of Denmark, UK and the Netherland and the second one composed of Germany and France. Belgium is now a no-converging country while Finland is integrated to group 1. For quarterly series, results are also very consistent with minor changes mainly due to one country moving from a non-converging path to a group or the merge of two groups. Interestingly, in every case when global convergence is observed, this convergence is robust.

The second point has been tested simply by ordering every country with respect to its last observation. As expected and predicted by the theory, results remain absolutely the same in every specification.

C.3 **Graphical evidence of (sigma) convergence**

In this section, we present an alternative chart which gives graphical evidence of the convergence process between 1890 and 2013. In Chart 5, we used the coefficient of variation (the square root of the variance divided by the mean) in order to have a hint on σ-convergence for GDP per capita and its components. However, there was still a risk for this coefficient to be mainly driven by outliers. For this reason we display, as a consistency test, the evolution of another measure of dispersion: the interquartile range which we normalized by the mean of countries belonging to quartiles 2 and 3. Each series has a very similar behavior as in Chart 5, suggesting that the obvious reduction observed is consistent with alternative measures of dispersion.

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[24] Another choice is the one of the sieving coefficient *c*, in step 3 of the algorithm (see appendix B) which we set to 0. However, according to Phillips and Sul, in the case of a small number of countries, this coefficient must be set to its highest possible value in order to avoid over-grouping some countries. The risk of finding too many groups is reduced by the Step 5 of the algorithm when we test for potential merge between different clubs (see Appendix 5).

[25] Result tables are available upon request and are only briefly described here.

Chart C1

Interquartile range divided by the mean of the countries belonging to quartiles 2 and 3.
Data for GDP per capita, TFP, Hours Worked, Employment Rate and Capital Intensity from 1890 to 2013

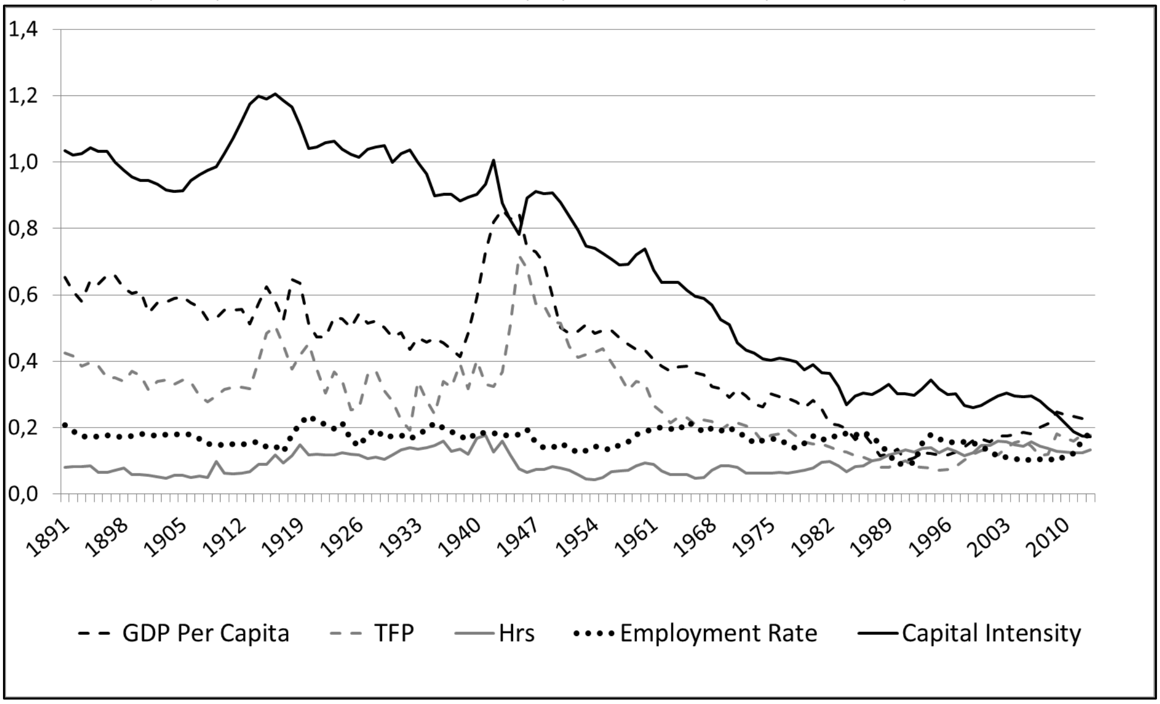

Table C1

Results when the Phillips-Sul Club Convergence test is used on the set of 17 countries in different sub-periods for TFP and Capital Intensity and for different values of parameters *α* and *δ*

See Table 1 for details

	TFP				Capital Intensity	
	High value of α	**Low value of α**	**High value of δ**	**Low value of δ**	**High value of δ**	**Low value of δ**
1895 – 2013	- (2.0)	- (2.0)	- (1.8)	- (2.1)	- (3.0)	- (2.6)
1895 – 1950	- (0.18)*	- (0.056)*	- (-0.06)*	- (0.20)	- (0.56)	- (0.27)
1950 – 2013	- (0.61)	- (0.66)	- (0.64)	- (0.62)	- (1.1)	- (1.2)
Original Values	**TFP**				**Capital Intensity**	
1895 – 2013	- (2.0)				- (2.8)	
1895 – 1950	- (-0.098)*				- (0.38)	
1950 – 2013	- (0.66)				- (1.1)	

Table C2

Results when the Phillips-Sul Club Convergence test is used on the set of 17 countries in different sub-periods for TFP and Capital Intensity and for different values of parameters α and δ (quarterly data)

See Table 1 for details

	TFP				Capital Intensity	
	High value of α	**Low value of α**	**High value of δ**	**Low value of δ**	**High value of δ**	**Low value of δ**
1974 – 2013	- (0.41)	- (0.22)	- (0.27)	- (0.29)	- (0.27)	- (0.35)
1974 – 1990	- (0.094)	**Gr1:** BE, CH, DE, DK, ES, FI, FR, GB, JP, NL, NO (0.16) **Gr2:** AU, CA, IT, SE, US (0.13) **NOCV:** PT	- (-0.13)*	- (-0.017)*	**Gr1:** AU, BE, CA, CH, DE, DK, ES, FR, IT, JP, NL, SE, US (0.13) **Gr2:** FI, GB (-0.38)* **NOCV**: NO, PT	**Gr1:** AU, BE, CA, CH, DE, DK, ES, FI, FR, IT, JP, NL, SE, US (0.024) **NOCV**: GB, NO, PT
1990 – 2013	**Gr1:** AU, BE, DE, DK, FR, GB, NL, NO, SE, US (0.57) **Gr2:** ES, IT, JP, PT (0.25) **NOCV**: CA, CH	**Gr1:** AU, BE, CH, DE, DK, FI, FR, GB, NL, NO, SE, US (0.30) **Gr2:** CA, ES, IT, JP, PT (0.021)	**Gr1:** AU, BE, CH, DE, DK, FI, FR, GB, NL, NO, SE, US (0.38) **Gr2:** CA, ES, IT, JP, PT (0.068)	**Gr1:** AU, BE, CA, CH, DE, DK, FI, FR, GB, NL, NO, SE, US (0.27) **Gr2:** ES, IT, JP, PT (0.21)	**Gr1:** AU, ES, FR, NL, PT, US (0.046) **Gr2:** BE, CA, DE, DK, FI, GB, JP (0.12) **Gr3**: CH, IT, SE (0.50) **NOCV**: NO	**Gr1:** AU, BE, DE, DK, FR, JP, NL, PT, US (0.12) **Gr2**: CA, CH, ES, FI, GB, IT, SE (0.18) **NOCV**: NO
Original Values	**TFP**				**Capital Intensity**	
1974 – 2013	- (0.28)				- (0.29)	
1974 – 1990	**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)*				**Gr1:** BE, CH, DE, DK, ES, FR, JP, NL, SE, US (0.11) **Gr2:** AU, CA, FI, IT (0.40) **NOCV**: GB, NO, PT	
1990 – 2013	**Gr1:** AU, BE, CH, DE, DK, FI, FR, GB, NL, NO, SE, US (0.39) **Gr2**: CA, ES, IT, JP, PT (0.006)*				**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	

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