GDP per capita and TFP in advanced countries: A long-term perspective over the past and the future

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Abstract:

Changes in GDP have been mainly driven by changes in the total factor productivity (TFP) growth rate during the 20th century. The goal of this paper is twofold. First, over the long period 1890-2015, we aim to characterize empirically the contribution of the quality of factor inputs and of technology diffusion indicators to TFP growth in four developed areas: the United States, the euro area, the United Kingdom and Japan. Two types of factor quality are considered: the average level of education and the average age of equipment. Two technological shocks corresponding to two general purpose technologies are investigated: electricity and information and communication technologies (ICT). Second, based on these results, we use user-friendly software to build two contrasting projection scenarios from 2015 to 2100. One scenario corresponds to the hypothesis of '*Secular Stagnation*' and the other to a new '*Technology Shock*', assuming the benefit of this shock on the TFP wave to be as large as that observed during the second industrial revolution.

JEL classifications: E20, N10, O11, O33, O43, O47, O57
Keywords: long-term growth, GDP per capita, productivity, total factor productivity.

1. Introduction

GDP per capita indicators are often used to analyze standards of living. This measure is however frequently criticized, notably in the famous Stiglitz, Sen and Fitoussi (2009) report, as it excludes many dimensions that impact citizens' well-being. For example, the work-leisure trade-off, inequalities in income or wealth distribution and sustainability of development and growth are not included in the calculation of GDP per capita. But as there is no consensus on how to account for these other dimensions and on how to weight each of them to build a synthetic well-being indicator, GDP per capita remains the most commonly used indicator in comparisons of standards of living and well-being.

Country comparisons based on GDP per capita can be made either in terms of levels or growth rates, these two dimensions being linked by convergence processes. The large literature devoted to this topic shows that GDP per capita levels do not necessarily converge across countries, even among advanced economies (see for example the seminal papers by Baumol, 1986; and Barro, 1991). Numerous factors can influence GDP per capita growth and convergence, and, among others, the main ones appear to be institutions, education and of course innovation and technological progress, which are in turn linked to education and institutions.[1]

Chart 1 shows the average GDP growth rate over different sub-periods of the whole 1890-2015 period for the four main developed areas that we will consider in this study: the United States (US), the euro area (EA),[2] the United Kingdom (UK) and Japan (JP). It also provides an accounting decomposition of GDP growth based on a simple Cobb-Douglas production function.[3] In this decomposition, the three main components of GDP growth are population growth, the growth in the number of hours worked per inhabitant and hourly labor productivity growth. The contribution of the number of hours worked per inhabitant to growth is itself decomposed into two sub-components: the employment rate and the number of hours worked per worker. The sum of the population and average working time per worker components corresponds to the overall contribution of the total number of hours worked to growth. And the contribution of hourly labor productivity growth is itself also decomposed into two sub-components: total factor productivity (TFP) and capital deepening.

Formally, $GDP = TFP.K^{\alpha}.(L.H)^{1-\alpha}$ with K being the stock of physical capital, L the number of workers, and H the average annual worktime per worker, so that *(L.H)* represents the total number of hours worked. Denoting the total population as *Pop*, we have:

$$GDP = \overbrace{TFP. \underbrace{\left(\frac{K}{LH}\right)^{\alpha}}_{Capital\ Deepening}}^{Hourly\ Labor\ Productivity} \times \underbrace{\overbrace{\left(\frac{L}{Pop}\right)}^{Employment\ rate} H}_{Number\ of\ hours\ worked\ per\ inhabitant} \times Pop$$

[1] On the role of education and institutions, see for example Barro (1991), Barro and Sala-I-Martin (1997), and, for more recent assessments, Aghion *et al.* (2008); Madsen (2010a and 2010b); Craft and O'Rourke (2013); and Acemoglu *et al.* (2014). On the impact of institutional and educational factors on innovation and technological progress see among others Aghion and Howitt (1998, 2006 and 2009).

[2] The euro area is defined in this paper as the aggregation of 8 of its largest countries: Germany, France, Italy, Spain, the Netherlands, Belgium, Portugal and Finland. This is a good approximation as these countries represent more than 93% of the euro area's 2010 GDP. See Bergeaud, Cette and Lecat (2016a) for more explanations.

[3] In this decomposition, we assume constant returns to scale and elasticity of output to capital that is constant and equal to 0.3 in the four economic areas for the whole period. For more details, see Bergeaud, Cette and Lecat (2015).

Log differentiating this last expression gives the decomposition that is represented in Chart 1.

Chart 1
GDP annual growth (as a %) and contributions (in pp) – Whole economy
Source: Bergeaud, Cette and Lecat (2015)

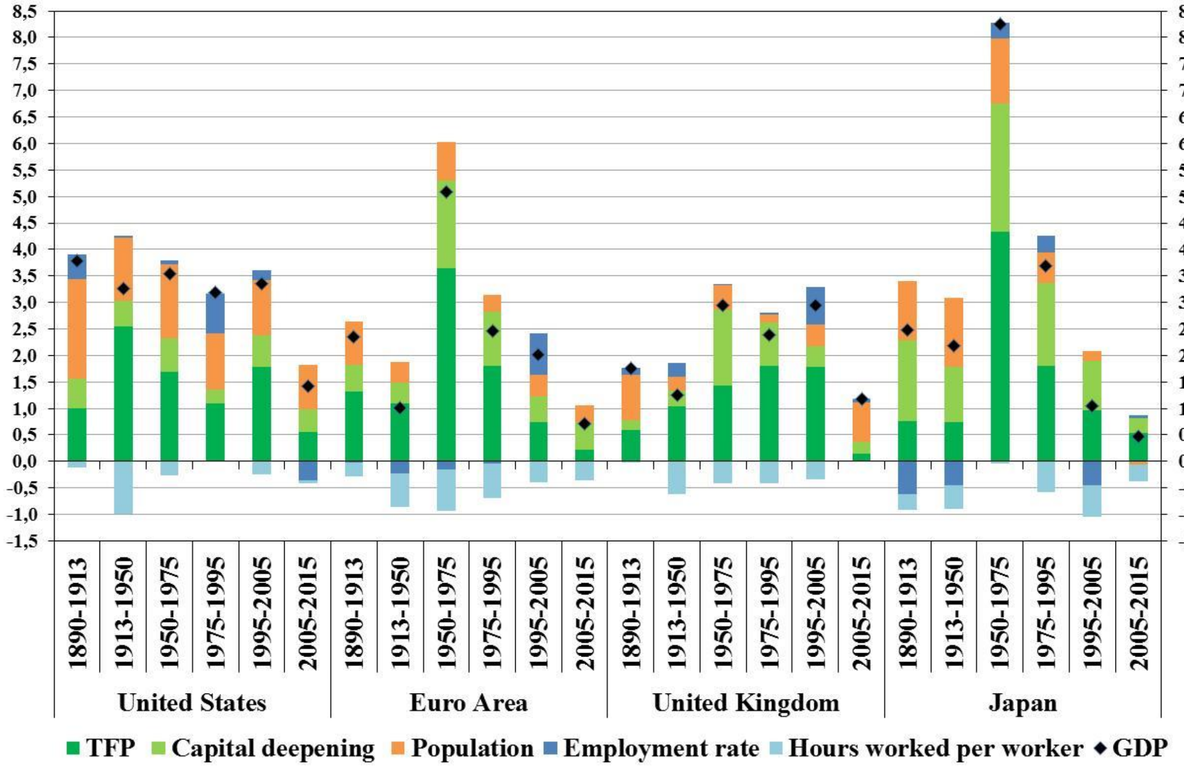

Chart 1 shows various interesting facts, among which:

- Hourly labor productivity growth (which is the sum of TFP growth and the growth in capital deepening) is the main contributor to GDP growth in the four economic areas considered. The overall contribution of hours worked (which corresponds to the sum of the contributions made by population, the employment rate and average working time) is generally small, if not null. Within hourly labor productivity growth, the contribution of the TFP sub-component is the biggest, with that of capital deepening being smaller. This TFP contribution varies a lot from one sub-period to another, with these variations generally being the main driver of changes in GDP growth. However, in our accounting we define TFP as a residual encompassing any variation of output that cannot be explained by the aggregation of physical capital and labor. As such, Chart 1 gives no real explanation of these large changes in GDP growth other than the small fluctuations explained by the working time component. This is why, as Abramovitz (1956) wrote, TFP is traditionally considered "*a measure of our ignorance*".

- GDP growth appears very low during the very last 2005-2015 sub-period in the four economic areas studied. And the main accounting origin of this low growth is a low contribution from TFP, especially when compared with previous sub-periods. Once again, our accounting framework cannot give any more explanation of this slowdown since it is driven almost entirely by a slowdown in TFP. These observations raise important questions: are we facing a risk of '*Secular Stagnation*'? This expression was coined by Hansen (1939) and was used again to describe the current situation notably by Summers (2014, 2015) and Eichengreen (2015). This low TFP growth is now well documented by several recent studies and concerns most of the advanced economies.[4] In our four areas, the slowdown of TFP can be observed from the end of the 1960s, and intensifies during the 1970s, the 1980s and the 1990s. One notable exception is the UK, which experienced very steady productivity growth from the 1950s to the late 1990s (see Broadberry and O'Mahony, 2004 for detailed explanations). As for the US, we clearly observe from the mid-1990s an acceleration due to faster improvements in the productive performances of information and communication technologies (ICT hereafter) (Jorgenson, 2001, was the first of numerous papers to stress this point). For some authors such as Gordon (2012, 2013, 2014, 2015), this situation could be the future of long-term productivity.

The goal of this paper is twofold. First, we characterize empirically the contribution of factor quality and technology diffusion indicators to TFP growth over the 1890-2015 period. In other words, we investigate the importance of some potential factors that can explain TFP dynamism in order to better understand changes in growth and to give insight into why TFP growth is low over the last 2005-2015 sub-period. We use results from Bergeaud, Cette and Lecat (2016b) to consider two factor quality dimensions: the average level of education level and the average age of equipment. Two technological shocks corresponding to two general purpose technologies are then looked at: electricity and ICT. Second, from these results, and using a tool previously developed by Cette, Lecat and Marin (2017), we build two contrasting growth scenarios from the current period to 2100. One scenario corresponds to the hypothesis of '*Secular Stagnation*' and the other one to the case of a '*Technology Shock*', assuming the impact of this innovation on TFP to be as large as the total contributions of electricity to TFP during the 20th century. This analysis is performed for our four major economic areas, i.e. the US, the EA, the UK and JP, and using annual data.

The construction of the necessary data is described at length in Bergeaud, Cette and Lecat (2016a, 2016b). Most of the data are available, and updates and construction details are reported. All of this can be found on a dedicated website (see Box 1 for more information).[5]

We make two main contributions to the existing literature. First, we show that production factor quality, especially education, and technological shocks indicators account for a large share of TFP growth, but at least half of the TFP waves of the 20th century remains unexplained. This suggests that there is scope for further analysis to explain the driver of TFP growth. Second, different credible future long-term growth scenarios show very contrasting results. This means that the future of long-term growth is highly uncertain. As we do not have complete knowledge and understanding of TFP drivers from the past, '*Secular Stagnation*' or high-growth scenarios corresponding to a large '*Technology Shock*' both remain possible.

The paper is organized as follows. Section 2 provides a deeper descriptive analysis of TFP growth waves. Section 3 analyses TFP drivers and presents the TFP decomposition, taking into account some factor quality and technological shock aspects. Section 4 comments on two contrasting growth scenarios, and Section 5 concludes.

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4 See for example for the US, Gordon (2012, 2013, 2014, 2015), or Byrne, Oliner and Sichel (2013), and for more advanced countries, Crafts and O'Rourke (2013), or Bergeaud, Cette and Lecat (2016a).

5 See www.longtermproductivity.com.

Box 1

Presentation of the website www.longtermproductivity.com

The database presented in this article (hereafter BCL database) has evolved continuously since its first version in 2013. As soon as the series are improved or new sources enable us to add new countries to the database, a new version of the BCL database is constructed. We have designed a website www.longtermproductivity.com where the latest version can be downloaded. For the available countries (currently 17: The USA, Japan, Germany, France, the United Kingdom, Italy, Spain, Canada, Australia, the Netherlands, Belgium, Switzerland, Sweden, Denmark, Norway, Portugal and Finland), the database is composed of series of GDP per capita, labor productivity, total factor productivity, average age of equipment and capital intensity. The basic series that were used to construct these measures (GDP, population etc.) are not currently available for download but can be sent on direct request by the authors. The sources that have been used are described in a file in the database. The website also provides an application that enables users to plot the latest series and to compare several countries (this application can be found at the following url: www.longtermproductivity.com/interact). All of the data available on the website can be freely used provided that they are properly acknowledged.

2. The TFP growth waves over the long period 1890-2015

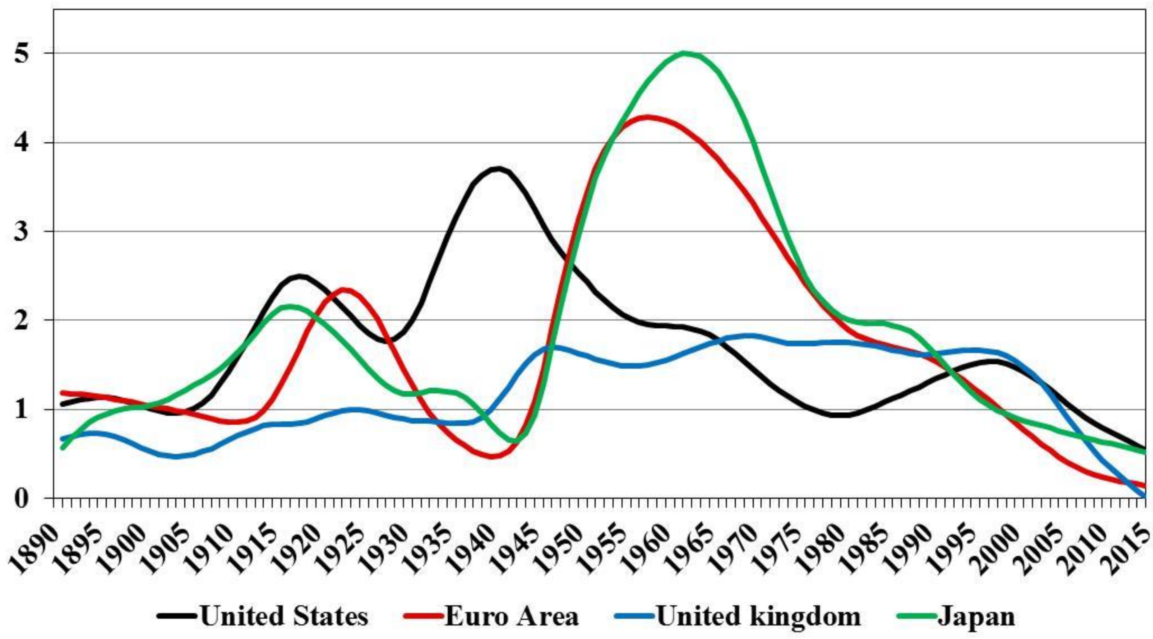
In order to establish long-run stylized facts in terms of TFP growth, we smooth the annual productivity growth rate over the whole period using the Hodrick-Prescott filter (HP). Given the very high volatility of the TFP indicator, the choice of the filter bandwidth, which sets the length of the cycle we capture, is of paramount importance. We decided to focus on 30-year cycles, which implies a value of 500 for lambda, according to the HP filter transfer function. Chart 2 shows smoothed TFP growth, from 1890 to 2015, for the US, the EA, the UK and JP.

Chart 2

Average annual growth rate of TFP - as a %

Smoothed indicator (HP filter, λ = 500) - Whole economy

Source: Bergeaud, Cette and Lecat (2016a).



We mainly distinguish five sub-periods from 1890 to 2015 (for more details, in particular regarding TFP levels, see Bergeaud, Cette and Lecat, 2016a):

- From 1890 to WWI, productivity grew moderately. Developed countries were at the end of the very long first industrial revolution linked to the spread of the stream engine and the development of the railways, etc. The UK enjoyed the highest level of TFP.

- After the WWI slump, the US experienced an impressive '*big wave*' of productivity growth, interrupted for some years during the Great Depression and identified by Gordon (1999) as the '*one big wave*', while other countries struggled with the legacy of the Great Depression and WWII. This productivity growth wave corresponds to the second industrial revolution (see Gordon, 2012, 2013, 2014, 2015) linked to the spread of large-scale use of electricity and the internal combustion engine, to the development of chemistry, namely oil-based chemistry and pharmaceuticals, and to the development of communication and information innovations (telephone, radio, cinema), etc. During this sub-period, the US took the lead in terms of TFP, which it has retained up to the present day.[6]

- After WWII, European countries and Japan benefited from the big wave experienced earlier in the US. During this catch-up process, TFP growth was declining in the US. This TFP slowdown appeared later, from the 1970s onwards, in the EA, the UK and JP.

- From 1995, the post-war convergence process came to an end as US productivity growth overtook that of other countries, although it did not return to the pace observed in the 1930s, 1940s and 1950s. Shorter and smaller than the first one, a second productivity wave appeared in the US and, in a less explicit way, in some of the other advanced countries. As documented in numerous papers, this productivity growth wave corresponds to the third industrial revolution linked to ICT (see for example, among others, Jorgenson, 2001, van Ark *et al.*, 2008, Timmer *et al.*, 2011, Bergeaud, Cette and Lecat, 2016a).

- From the mid-2000s, before the beginning of the Great Recession, TFP growth decreased in all countries. The current pace of TFP growth appears very low compared to what was observed previously, except during the world wars. Some analyses regard it as structural (see for example Gordon 2012, 2013, 2014, 2015) and others as a short step before a new acceleration (Pratt, 2015; Mokyr *et al.,* 2015; or Brynjolfsson and McAfee, 2014), and even, but only partly, as mismeasurement (see for example Byrne, Oliner and Sichel, 2013).[7] Other explanations of this slowdown are also plausible (for a survey, see Cette, 2014, 2015).

3. The TFP drivers

We try to explain TFP growth by changes in factor quality and by technological shocks (see Bergeaud, Cette and Lecat, 2016b, for details concerning estimation procedures).[8] Two types of factor quality

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[6] Some countries have a higher TFP level over the period for specific reasons, for example Norway due to a specific sectoral composition.

[7] Syverson (2016) and Byrne, Fernald and Reinsdorf (2016) argue that measurement error in the growth of the ICT sector cannot explain the current observed productivity slowdown. Aghion *et al.* (2017) estimate that at most one sixth of the decrease in the productivity growth rate from the 1996-2005 period to the 2005-2013 period could be attributed to mismeasurement.

[8] Estimates are all made using instrumental variables approaches on a panel of 17 countries over the period 1890-2010, and 1913-2010 in the case of electricity.

dimensions are considered: the average level of education and the average age of equipment capital stock. And two technological shocks corresponding to two general purpose technologies are examined: electricity and ICT.

Regarding education, which is an indicator of labor force quality, we use new series of educational attainment provided by van Leeuwen and van Leeuwen-Li (2014) and available yearly from 1870 to 2010. They correspond to educational attainment for the population over 15.[9] The average duration of schooling increases continuously over the period in the four economic areas. At the end of the 19th century, Japan was the area with the lowest level of educational attainment with less than 2 years in education among its population, while the US, the EA and the UK recorded about 4 years of education. At the end of our dataset, the EA is the area with the lowest level of education, with an average duration of 11.5 years, behind the US, the UK and Japan which are on about 12.5 to 13 years. 13 years seem to be a maximum for the average duration of schooling, which means that TFP gains from the increase of this duration belong to the past for the US, the UK and Japan, and that few gains remain to be obtained from this for the EA.[10] The rather low level of education achieved for the EA hides large disparities, with some European countries like the Netherlands, Germany and France having levels comparable to the US, and southern European countries (Spain, Portugal and Italy) lagging behind, with the average duration of schooling in Portugal being below 8 years in 2010.

Many studies, using micro or macro approaches, have focused on estimating the returns on education, corresponding to the productivity gains associated with an average increase of one year in educational attainment. There is a broad empirical consensus in most micro studies on a private return on education of between 4% and 8% in developed countries. Our estimate results indicate an elasticity of TFP to the average duration of education of 4.9%, which means that an increase of one year in educational attainment would increase the TFP by 4.9%. From this result, we can attribute to the 9 to 11 years' increase in educational attainment in our four different areas a rise in TFP of 44pp to 54pp over the long period starting in 1890.

We have calculated the average age of the equipment capital stock, which is an indicator of the quality of this factor and should therefore be incorporated into the production function.[11] This simply corresponds to the intuitive idea of a vintage effect: older capital is expected to be less productive than newer capital, as suggested by Solow (1959, 1962) and developed subsequently in numerous papers. It appears that variations in the average age of equipment differ across areas: the range of these variations is 5 years for Japan (from a minimum of 4 years to a maximum of 9 years), 4 years for the EA (from 5.3 years to 9.3 years), and 3 years in the US (from 5.7 years to 8.7 years) and the UK (from 6 years to 9 years). The average age increased strongly during the Great Depression in the US, which weighed heavily on investment; it greatly decreased during WWII due to the war effort, and more modestly during the ICT wave, as new investment was needed to incorporate the new technology. In the EA and the UK, it increased strongly during WWII, as the conflict depressed investment, and decreased in the post-war reconstruction period. It has been on an increasing trend since 1990 in Japan due to the banking crisis, and since the financial crisis in other areas, as credit constraints and low demand prospects weigh on investment. Smaller contra-cyclical fluctuations can be observed.

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[9] The calculation starts with primary school and does not include kindergarten or any other type of education received before 6.

[10] Gains from education could be now sought in the quality of education and continuous education, with a potential significant impact of ICT in this area.

[11] We assume that depreciation of each element of capital follows a geometric distribution where the probability of depreciation is δ. This distribution is memoryless, that is, the probability of depreciation is independent of the age of capital, and the average life expectancy of capital is then equal to $\frac{1}{\delta}$. We assume that $\delta = 0.10$.

As with education, many studies, using micro or macro approaches, have estimated the impact of the average age of capital on TFP. The results usually obtained correspond to a negative impact on TFP of an increase of one year in the average age by -1% to -6.5%, these results mainly being concentrated around -4%. Our estimated value corresponds to an impact of -3%, which means that average age variations during the period, from the minimum to the maximum values of capital age, would have changed TFP level by 15% in JP, 12% in the EA, and 9% in the US and the UK.

To measure the diffusion of technology over the whole period, we have drawn on the CHAT database constructed by Comin and Hobijn (2009). This database provides annual estimates of the diffusion of more than 100 technologies for a large set of countries. We have selected one technology which is often considered to be representative of the development of technologies during the 20th century, i.e. the production of electricity in kWh (see Comin *et al.*, 2006a and 2006b). Data have been completed with series using the World Development Indicators of the World Bank up to 2013 and have been standardized by total population. This indicator has increased over time in the four economic areas, but this increase slowed from the 1970s onwards. In line with the literature that focuses on the impact of electricity on US productivity growth (Bakker *et al.*, 2015, among others), the take-off of electricity in the US started at the beginning of the 20th century and accelerated during the 1920s. The UK lags just behind with a take-off that started in the 1930s, while the EA and Japan started to massively adopt electricity after WWII. The take-off date depends both on the fall in electricity prices and on a reorganization of the production process to fully benefit from electricity (David, 1990).

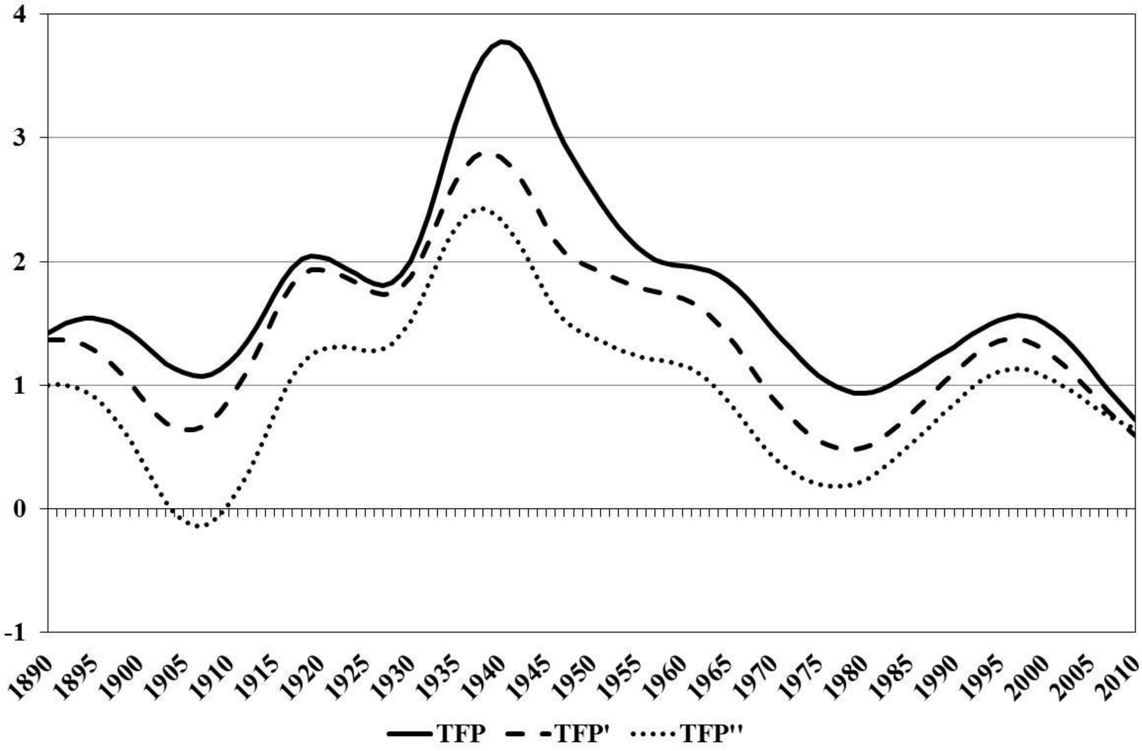
We make the assumption that the elasticity of TFP to the ratio of electricity per inhabitant is constant over time. The constant elasticity assumption, as it has been also chosen for the impact on productivity of education or capital age, appears preferable to an *ad hoc* rule. Our results indicate that a 1% increase in electricity production per inhabitant would lead to a 0.079% increase in TFP. With this elasticity, it appears that, from 1913 to 2010, the increase of electricity production and use would have increased TFP by 31pp in the US, 35pp in the EA, 37pp in the UK and 46pp in Japan.

Concerning the second measure of technology, we have taken the ratio of the stock of ICT capital to GDP in current value. To compute this ratio, we have drawn on the work of Cette *et al.* (2015) based on investment data provided by the OECD. ICT is split into three products: hardware, software and communication equipment, and capital stock is computed using a permanent inventory method. Note that for ICT, we have used a measure of stock and for electricity we have used a measure of production. However, electricity production should reflect productive capacity, as electricity cannot be stored, electricity imports and exports are low compared to country production, and utilization of productive capacities should not create a systematic bias. It appears that ICT capital stock took off in the 1980s in the US, with a peak at the end of the 1990s. This early diffusion of ICT in the US can be explained by levels of education and low market rigidities in the US (Cette and Lopez, 2012). ICT diffusion accelerated at the end of the 1990s in Japan and the UK, while the EA lagged behind due to its stringent employment protection legislation and product market regulation.

Our estimates indicate that a 1pp increase in the ratio of ICT capital stock to GDP would lead to an increase of 1.56% in TFP. With this elasticity, it appears that, from 1913 to 2010, ICT diffusion as a production factor would have increased TFP by 14% in the US, 9% in the EA, 11% in the UK and 13% in Japan. This impact is of course concentrated in the post-1950 period.

From these results, we build two new TFP indicators. TFP’ is TFP corrected for the impact of the duration of education and changes in average capital equipment age. TFP’’ is TFP’ corrected for the impact of electricity production per inhabitant and changes in the ICT capital to GDP ratio. Chart 3 represents TFP, TFP’ and TFP” smoothed growth over the period for the US.[12]

Chart 3
Average annual growth rate of different indicators of TFP for the US - as a %
Smoothed indicator (HP filter, λ = 500) - Whole economy. TFP is the usual residual of a Cobb-Douglas production function taking into account only capital and labor as production factors. TFP’ excludes the impact of education and age of capital, and TFP’’ also excludes the impact of electricity and ICT.
Source: Bergeaud, Cette and Lecat, 2016b.



From a comparison of TFP and TFP’ growth, we see that variations in human capital and the age of capital contribute significantly to TFP growth. Over the whole 1890-2010 period, human capital and the age of physical capital together account for 21% of the US's TFP growth, 17% for the EA, 25% for the UK and 26% for JP. However, it appears that the amplitude of TFP’ growth does not differ a lot from that of TFP. In particular, the *‘one big wave’* that occurred during the 20th century is still persistent with respect to the US and this is also the case for the wave in the mid-1990s. This result is robust to different sets of credible values concerning the elasticity of TFP to the duration of education and to the average age of capital. Nevertheless, education significantly contributed to the first productivity wave in the US, with a contribution of 0.42 percentage point (pp) per year during the 1913-1950 period, only slightly decreasing in the following periods (0.38 pp in 1950-1974 and 0.34 pp in 1974-1990). Hence, the early opening-up of education to the masses in the US yielded a lasting contribution to productivity and partly explains the US's lead. Indeed, the increase in the contribution of education appears one period later, in the 1950s, in the EA and the UK. In Japan,

[12] Results are qualitatively the same for the other areas. These other results can be obtained from the authors on request.

education posts a significant contribution throughout the century due to the initial very low level of education. The age of capital makes a significant positive contribution mainly during the reconstruction period after World War II in the EA and Japan, and also in the UK. Conversely, it has made a significant negative contribution since the 1970s in the EA and Japan. In the four areas, equipment has aged from the 2000s, with a negative contribution to TFP growth.

The TFP growth waves are still persistent for TFP'', which is also corrected for the impact of the two GPT technological shocks considered (electricity and ICT), especially as far as the '*one big wave*' is concerned. However, the amplitude of this '*one big wave*' has been reduced and is almost 40% lower for TFP'' than for TFP'. Although the difference in contribution is not very large across areas, the spread of electricity contributed significantly to the US's advance on the EA, as its contribution peaked in the 1913-1950 period, while it increased during the 1950-1974 period in the EA. The UK appears not to have lagged in terms of the diffusion of electricity, with a very large contribution in the 1913-1950 period. Broadberry and Crafts (1990) trace the productivity lead that the US took over the UK during this period rather to barriers to competition allowing high cost producers to remain in business. The contribution of ICT to TFP growth appears to be smaller than that of electricity in all of the areas. This result seems consistent with, for example, those of Crafts (2002), or Jalava and Pohjola (2008).

The low contribution of ICT diffusion to the second productivity wave could have several explanations. Two of them seem interesting to underline here:

- Due to the price decrease of this type of product, investment in ICT can accelerate the capital deepening process in ICT-using industries, leading to an increase in capital intensity and hence in labor productivity, but not necessarily in TFP. But national accounts take only partially into account ICT investment price indexes embodied technological progress, which is not fully included in increases in investment volume and falls in investment prices (see the synthesis by Van Ark, 2016, on these aspects). Consequently, the accounting split between capital deepening and TFP within labor productivity growth is biased, the role of the capital deepening component being undervalued and, conversely, the role of TFP growth being overvalued.

- ICT investment data compiled by national accountants (and taken into account here as ICT investment) underestimate productive ICT expenditure. Indeed, spending on ICT is regarded as investment only when the corresponding products are physically isolated. Therefore, generally speaking, ICT that is included in productive investment (for example machine tools or robots) is not counted as ICT investment but as intermediate consumption of companies producing these capital goods. Beretti and Cette (2009) and the Cette *et al.* (2016) correct macro ICT investment data by considering intermediate consumption in ICT components integrated in non-ICT productive investment. Their main result is that the amount of '*indirect ICT investment*' appears not to be insignificant.

Regarding the productivity slowdown observed during the 2000s, analyses carried out by the OECD at the firm level suggest that this slowdown does not appear be observed for the most productive firms, in other words, the productivity frontier (see Andrews, Criscuolo and Gal, 2015). The productivity slowdown appears to be a diffusion problem of the best performances from the frontier to the laggard firms. This diffusion problem seems to hinge on the nature of innovations at the current juncture, with intangible capital being more difficult to replicate, or on a winner-takes-all phenomenon in ICT sectors. But then the issue is to explain why such performance diffusion difficulties appear to have become worse at the same time in all developed countries, which are at different stages of development, education, ICT use… Work in progress at the Banque de France on French firms confirms the OECD results but suggests alternative explanations. The cleansing mechanisms may indeed have become weaker and weaker. One explanation being tested is that this weaker cleansing mechanism could at least partly be explained by a decline in real interest rates and less expensive capital, which allow low productive firms to survive and highly productive firms to thrive. Less expensive capital lowers the return on capital expected from firms and allows innovative firms to take on more risks. Various recent papers have already confirmed that such an explanation would be relevant for Southern European countries as Portugal, Italy and Spain (see for example Reis, 2013, Gopinath *et al.,* 2015, Gorton-Ordonez, 2015, or Cette, Fernald, Mojon, 2016).

Nevertheless, the drivers of TFP growth continue to remain largely puzzling. For this reason, the future of productivity and GDP growth is very hard to forecast and different contrasting scenarios are still credible.

4. Two contrasting growth scenarios for the future

Two very different growth scenarios are put forward, using a tool built and described in Cette, Lecat and Marin (2017), in order to illustrate how much possible future outlooks differ.

In the two scenarios, we use OECD employment projections until 2060 and assume that from 2060 to 2100 the contribution of employment remains around 0.5 pp per year. Regarding the US, the hours worked per worker decrease by 0.1% per year until 2060, which corresponds to the evolution observed during the most recent historical sub-period 2005-2014, and from 2060 onwards, hours worked per employee stabilize. For non-US areas, growth in the hours worked per worker remains on its 2005-2014 trend until 2060, when it stabilizes. In the US, the average length of education is assumed to be constant at 12.8 years. For non-US countries, education and regulation converge to US levels over the 2015-2030 sub-period, which allows an acceleration of TFP convergence to the US level. For the UK, we have not included a specific treatment with regard to Brexit, as this shock is hard to calibrate, but it creates an additional downward risk on all the scenarios presented above. The two scenarios ignore negative shocks comparable to the two world wars of the 20th century, and ignore the issues of potential energy shortages or climate change that could severely affect productivity in the future.

In the first scenario, termed *'Secular Stagnation'*, US TFP growth stays indefinitely at the low level observed both before (1974-1990) and after (2005-2014) the ICT productivity growth wave associated with the ICT third industrial revolution. In the second, called '*Technology Shock'*, the US enjoys another large productivity growth wave associated with a third industrial revolution based on ICT or other technologies. The underlying TFP growth is then assumed to return to the level observed during the 1990-2005 sub-period. We add to this trend a technology shock lasting over four decades and equivalent to the TFP contribution of electricity during the second industrial revolution in the 20th century. This second optimistic scenario could correspond to the idea that ICT have not yet yielded their full productivity benefits. Previous GPTs took a very long time to be fully profitable: between the first practical design of a dynamo in 1867 and the actual conversion of industrial processes to electricity in the US, which only took off in 1914-1917, 50 years elapsed and the full productivity benefits were only felt 70 years afterwards (David, 1990). So these two scenarios differ regarding this possible second productivity wave that could be expected from ICT, with Gordon (2014) on the pessimistic side and, among others, Brynjolfsson and McAfee (2014), Mokyr (2015) or van Ark (2016) on the optimistic side.

In the '*Secular Stagnation*' scenario over the period 2015-2100, US GDP growth averages 1.5% (see Chart 4), with a contribution of 0.6pp from TFP, 0.5pp from capital intensity and 0.4pp from hours worked (itself decomposed into a contribution of 0.5pp from employment and -0.1pp from hours worked per worker). In non-US areas, average GDP growth is below 1.5% in the EA and as low as 1% in Japan, below US average growth because of low employment growth. In the UK, due to higher employment growth, average GDP growth would be slightly above the US. This '*Secular Stagnation*' scenario corresponds to low future GDP and productivity growth in developed countries. It means that the different headwinds identified by Gordon (2012, 1013) will be challenging to face. This scenario would be alarming, leading to risks of social and possibly political instability.

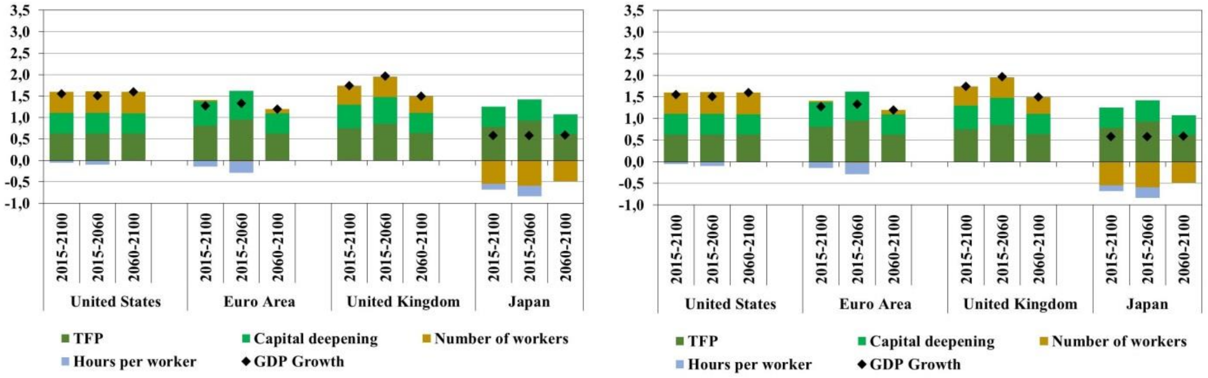
In the '*Technology Shock*' scenario, the yearly US GDP growth rate accelerates to 3% over the 2015-2100 period, with a 1.4pp contribution from TFP, 1.1pp from capital intensity and 0.5pp from employment (see Chart 4). Thus, the contributions from TFP and capital intensity are more than double those in the '*Secular Stagnation*' scenario. Over the whole 2015-2100 period, the GDP growth rate would come out at a yearly average of 2.5% in the EA, 3.0% in the UK and 1.9% in Japan. This pace would correspond to the 1974-1990 trend growth rate for the EA, and the 1950-1974 rate for the UK, but would remain much lower than any 20th century trend growth rate for Japan, as the overall contribution of labor would be negative. In this '*Technology Shock'* scenario, there is no doubt that the different headwinds set out by Gordon (2012, 1013) would be easy to face, in the US and also in non-US countries, if there were a convergence of education and regulation to US levels.

The large contrast between these two extreme scenarios illustrates the wide range of possible average GDP growth to the end of this century.

Chart 4

Average yearly GDP growth and contributions under the '*Secular Stagnation'* (left-hand side) and the '*Technology Shock*' (right-hand side) hypotheses.

Source: Authors' computations based on Cette, Lecat and Marin (2017).



Notes: These charts present average yearly GDP growth. GDP growth is decomposed into the contribution of TFP, capital intensity, the number of employees (labor) and hours worked per employee (hours). In this decomposition, we assume a Cobb-Douglas function, with constant returns to scale and elasticity of output to capital that is constant and equal to 0.3 in the four economic areas over the whole period. For more details, see Cette, Lecat and Marin (2017). The contribution of 'Number of workers' corresponds in these charts to the sum of the contributions of 'Population' and 'Employment rate' in Chart 1.

5. Conclusions

Long-term views of GDP per capita are useful to characterize long-term developments in living standards. In this study, we use an original database over the long 1890-2015 period for the four main developed areas: the US, the EA, the UK and Japan. The construction of the database is described in Bergeaud, Cette and Lecat (2016a). We decompose GDP growth into its main components through an accounting breakdown. These components are TFP, capital intensity, working time, employment rate and population. It appears clearly that changes in TFP growth are the main driver of changes in GDP growth. So, we try to go further in the explanation of the changes in TFP growth. The analysis is carried out on annual data.

The goal of the paper is twofold. First, we characterize empirically the contribution of factor quality and technology diffusion indicators to TFP growth. In other words, we evaluate some of the TFP drivers in order to better explain changes in TFP growth and low TFP growth over the last sub-period 2005-2015. Two types of factor quality are considered: the average level of education level and the average age of capital stock. Two technological shocks corresponding to general purpose technology innovations are considered: electricity and ICT. Second, from these results, and using for this the user-friendly software designed by Cette, Lecat and Marin (2017), we build two contrasting growth scenarios from the current period to 2100, the end of the century. One scenario corresponds to the hypothesis of '*Secular Stagnation*' and the other to a new '*Technology Shock*', assuming the benefit of a TFP growth wave as large as the one that accompanied the second industrial revolution.

Our main contribution is twofold. First, production factor quality and technological shock indicators explain a large part of TFP growth, but at least half of the TFP waves remains unexplained, which means that we have to go further in future analysis to explain growth. Second, different credible future long-term growth scenarios are very contrasting, which means that the future of long-term growth is highly uncertain. As we do not have complete knowledge and understanding of TFP drivers, '*Secular Stagnation*' and high-growth scenarios corresponding to a large '*Technology Shock*' they seem possible.

But policies may influence TFP and GDP per capita growth. Relevant ones are policies that support innovation and ones which allow faster productivity benefits from technological shocks, and for example policies to reduce anticompetitive barriers on the product market, or that introduce more flexibility on the labor market, and of course policies to increase 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). The challenge in the coming years for the four economic areas considered in this analysis will be not to miss the opportunities arising from a possible new TFP growth wave linked to a technology shock which starts to appear. But there are also policies impacting labor supply, and compared to the US, the GDP per capita in the EA suffers from lower employment rates. But the increase of the participation rate in the EA over the two last decades also illustrates the large role played by policy.

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