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PRODUCTIVITY TRENDS IN ADVANCED COUNTRIES BETWEEN 1890 AND 2012

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In order to examine productivity waves and convergence processes, we study productivity trends, trend breaks, and levels for 13 advanced countries between 1890 and 2012. We highlight two productivity waves, a big one following the second industrial revolution and a smaller one following the ICT revolution. The convergence process has been erratic, halted by inappropriate institutions, technology shocks, financial crises, and above all wars, which led to major productivity level leaps, downwards for countries experiencing war on their soil, and upwards for other countries. Productivity trend breaks have been identified following wars, global financial crises, global supply shocks, and major policy changes. The upward trend break for the U.S. in the mid-1990s has been confirmed, as has the downward trend break for the euro area in the same period.

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1. Introduction

Productivity is one of the main determinants of living standards and has thus always received much attention in economic literature. The focus has been placed on two aspects: productivity growth factors, and productivity convergence processes at the country level.

Technological progress appears to be the main driver of productivity growth. Nevertheless, the way this technological progress improves productivity depends on numerous factors. For a country at the technological frontier, that is, the productivity leader, productivity improvement depends on innovations,

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education, and institutions, and these three dimensions are interdependent (for a complete overview, see Aghion and Howitt, 1998, 2009; Crafts and O'Rourke, 2013). Ferguson and Wascher (2004) showed in a detailed way how each wave of productivity growth corresponded in the U.S. over the last century to an interaction between technological shocks and adapted institutions, which include education of the working age population, regulation of labor, product, and financial markets as well as the quality of the State (i.e., level of corruption, quality of justice, etc.) and, as stressed by Barro and Sala-i-Martin (1997), property right protection. For the followers (i.e., countries behind the technological frontier), the productivity growth process seems easier as it is cheaper for them to copy innovations than for a leading country to innovate. In this respect, it could be concluded that a catch-up process, that is, productivity convergence, would necessarily take place, but this is not what is observed. Indeed, copying innovation requires adapted institutions and appropriate education investments (Vandenbussche *et al.*, 2006). As a consequence, due to inadequate institutions, the followers' productivity convergence process toward the level of the leading country often stops, or even reverses. To this end, Crafts and O'Rourke (2013) show that the productivity leader can change over time, that productivity growth is characterized by waves, and that productivity convergence is not guaranteed for the followers, and that all these aspects are explained by the interactions of institutions, education, and innovations.

Numerous studies have presented, using a large dataset of countries, comparisons of productivity growth over a long period (see, among others, Islam, 2003; Madsen, 2010a, 2010b; and for a survey, Crafts and O'Rourke, 2013). Their results are consistent with the analyses mentioned above. For the last two decades, attention has mainly focused on the explanation of the productivity surge in the U.S. and the productivity slowdown in Europe in the mid-1990s (see, among others, Jorgenson, 2001; Van Ark *et al.*, 2008; Timmer *et al.*, 2011), and the productivity slowdown in the U.S. in the mid-2000s (see, among others, Gordon, 2012, 2013; Byrne *et al.*, 2013). The two contrasting breaks of the 1990s (upward in the U.S. and downward in Europe) seem well explained by a dynamic interaction between innovation (related to ICTs) and institutions. However, the productivity slowdown in the United States, preceding the current Great Recession, is too recent to benefit from a large range of analyses.

In order to examine productivity waves and convergence processes, this paper studies productivity trends and trend breaks over a long period using a broad set of industrialized countries. Two productivity indicators are considered: labor productivity per hour worked (denoted LP), and total factor productivity (TFP). Waves of productivity growth are characterized using Hodrick–Prescott filtering (denoted HP), and productivity trend breaks are detected using the Bai and Perron (1998) statistical methodology.

The dataset is composed of 13 countries: those in the G7 (the United States, Japan, Germany, France, the United Kingdom, Italy, and Canada); the other two largest euro area countries (Spain and the Netherlands); and four other countries whose productivity is interesting to analyze for specific reasons (a high productivity level at the beginning of the period for Australia, a specific European economic integration for Finland, a particular industry structure for Norway, and the role of structural policies for Sweden). In addition, here, we proxy the euro area through the aggregation of Germany, France, Italy, Spain, the Netherlands, and Finland.

The analysis is carried out over the period 1890–2012 using annual data and also, from 1960 onwards, using quarterly data.[1] However, in order to build capital stock series, using a perpetual inventory method, we used information on investment over a longer period when available. The main contribution of this analysis is that it is conducted over a long period, on a broad set of countries, with data expressed in terms of purchasing power parity and taking account, where possible, of consistent assumptions that allow for levels and growth comparisons across countries for each of the two productivity indicators.

This study yields numerous results regarding productivity developments, notably: (i) Over the 1890–2012 period as a whole, we observe two productivity growth waves, the first big one corresponding to the second technological revolution (use of electricity, the internal combustion engine, chemical production, etc.), and the second, smaller and shorter, to the ICT technology revolution. (ii) In the U.S., the first wave corresponds to a productivity acceleration during the 1930s and the 1940s and a deceleration during the following two decades; the second wave corresponds to a productivity acceleration during the 1980s and the 1990s and a deceleration afterwards. This latest deceleration raises the question as to the future contribution of the ICT revolution to productivity enhancement. Other countries benefited from these two productivity growth waves with a lag, and in a less explicit way for the second wave. The length of this lag varies from one country to another. (iii) The productivity leader changed during the period, from Australia and the U.K. to the U.S. during the first part of the twentieth century. Also, for highly specific reasons, a Norwegian, Dutch, and French leadership was observed, at least for a few years at the end of the twentieth century.[2] (iv) There is no global and permanent convergence process regarding the level of productivity, and divergence processes or stable gaps often persist during long sub-periods; (v) General productivity breaks occur in all countries at specific moments, such as world wars, global supply shocks (such as the petrol shock of the 1970s), or global financial crises (such as those of the end of the 1920s or the end of the first decade of the 2000s). (vi) Country-specific productivity breaks appear, which can be linked to idiosyncratic shocks such as policy changes (for example, the implementation of structural reforms in Canada and Sweden in the 1990s) or technological leaps (such as the early acceleration of the ICT technological shock in the U.S. during the 1990s).

As far as comparisons are possible, these results are consistent with those of other analyses usually focusing on one or a limited number of countries and over

[1]1890 was selected as a starting date in order to allow for a break before World War I and in order to have long enough investment series to initialize the capital series (cf. Appendix 1).

[2]These specific reasons relate to the significant industry specialization in high-productivity activities (such as petrol, wood, and fishing) for Norway and the relatively short average working time and low employment rate with decreasing output returns of these two variables for Norway, the Netherlands, and France.

shorter periods (see, for example, the survey of numerous analyses proposed by Crafts and O'Rourke, 2013).

Section 2 presents the two productivity indexes and the data used in the analysis. Section 3 describes productivity waves while Section 4 studies the productivity trends and their breaks. Section 5 concludes. Data source are given in Appendix 1, specific details about our methodology in Appendix 2, and robustness tests in Appendix 3. All appendices are available online. In addition, for the sake of clarity, we chose to display only the graphs concerning the main economic areas (the U.S., the euro area, Japan, and the United Kingdom). Other graphs are available in our online appendix.

2. Productivity Indexes, Data, and Methodology

The productivity analysis is conducted using two indexes (Section 2.1), computed for 13 countries and the euro area over the period 1890–2012. This analysis requires few series but must be calculated over a long period, representing the main challenge of constructing this database (Section 2.2). This dataset is then used to econometrically estimate breaks in trends (Section 2.3).

2.1. *The Two Productivity Indexes*

We considered 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*) growth is itself decomposed in two sub-components, following Solow's "growth accounting approach" (Solow, 1956, 1957): total factor productivity (*TFP*) growth and the capital to labor ratio (K / L) growth multiplied by the elasticity of GDP to capital (α). This second sub-component is usually termed the capital deepening effect. The total factor productivity indicator (*TFP*) is the ratio of GDP (Y) to an aggregation 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) used 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.

2.2. *The Data*[3]

The two productivity indexes (*LP* and *TFP*) are computed over the period 1890–2012 for 13 developed countries. These 13 countries correspond to those in the G7 (the United States, Japan, Germany, France, the United Kingdom, Italy, and Canada), the other two largest euro area countries (Spain and the Netherlands), and four other countries whose productivity is interesting to analyze for specific reasons: a high productivity level at the beginning of the period for Australia, a specific European economic integration for Finland, a particular industry structure for Norway, and the role of structural policies for Sweden. In addition, they are also computed for a euro area reconstituted here by the aggregation of Germany, France, Italy, Spain, the Netherlands, and Finland. This approximation seems acceptable as these six countries represent together, in 2012, 84 percent of euro area GDP.

To compute the two productivity indexes over this long 1890–2012 period, three basic series are needed for each country: GDP (Y), labor (L), and capital (K). Regarding labor (L), we need data on total employment (N) and working time (H). The capital indicator is constructed by the perpetual inventory method (PIM) applied to each of the two components (equipment KE and buildings KB) with the corresponding investment data (IE and IB). To this end, where possible, very long-term information on investment is used. As in Cette *et al.* (2009), the depreciation rates used to build the capital series by the PIM are 10 percent for equipment and 2.5 percent for buildings. It appears that the results of the study are robust to this choice and kept roughly stable for other realistic depreciation (see Appendix 3 for robustness tests). Finally, damage occurring during World War I (WWI), World War II (WWII), earthquakes in Japan, and the civil war for Spain are, where such information is available, taken into account to build the capital series. The fact that the same assumptions are made for all countries in the database to build the capital series is of course important to compare *TFP* levels and developments.

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 (see Appendix 3).

The starting database was that built by Cette *et al.* (2009) for the United States, Japan, France, and the United Kingdom over the 1890–2006 period. We have updated and considerably enlarged this first database. We have tried to make the best use of the estimates of long aggregate historical data series (e.g.,

[3]Data sources and construction are detailed in Appendix 1, available online.

Maddison, 2001, 2003) on GDP, employment, working time, and investment (in two products, equipment, and buildings). For the most recent decades of the analysis, we used national accounts data if available. For others, 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.[4] We may nevertheless consider that the orders of magnitude of our estimates and the ensuing large differentials in productivity levels and growth rates are fairly reliable and meaningful. Series for GDP and capital are given in 2005 constant national currencies, and converted to U.S. dollars at purchasing power parity (PPP) with a conversion rate from the Penn World Tables.

2.3. *Methodology*[5]

We define productivity trends as linear time trends of log productivity between two break dates. First, we test the hypothesis of stationarity, which would mean that productivity has a constant trend over the whole period. Second, we implement the standard (Bai and Perron, 1998) methodology, which allows us to compute simultaneously the number of breaks, their dates, and trends. This methodology requires setting a minimum number of observations between two breaks: we chose to set this parameter for annual data at 6 percent of the total number of observations, which accounts for approximately 7 years. In order to limit border effects and improve the performance of the test through a larger number of observations, we used quarterly data from 1960 onwards and set the parameter at 10 percent (5 years), with a maximum number of four breaks. To merge the break dates from annual and quarterly series, we ran the test separately on annual data for the whole period and on quarterly data. Then, after the first break in the quarterly series, we kept the break dates identified in the quarterly series only. We removed the remaining last break date of the annual series if it was located less than five years before the first break year of the quarterly data.

WWI and WWII and the Spanish Civil War led to disruptions in the production process and statistical sources, whose intensity varied across countries. Data may hence be unreliable and volatile during the war periods, but also for some years afterwards as normalization can take several years. Countries not directly involved may also be affected through trade disruption or anticipated conversion to a war economy. Therefore, although it is not relevant to apply the general trend break methodology, a consistent statistical procedure is necessary for assessing the length of the war disruption period for each country beyond the official war period. Hence, we added dummy variables for war periods, allowing for breaks in the productivity trend and level. Finally, a possible break date at the end of each war period has been added.

[4]Take, for example, the distance of these hypothetical constant border countries from the economic reality for Germany, and even Italy and France over the period 1890–2012.

[5]Statistical details and computation are given in Appendix 2, available online.

3. Productivity Waves: Innovation and Convergence over the Twentieth Century

Before characterizing productivity trend breaks through a statistical approach, we analyze the main productivity growth waves. These waves provide a useful and simple representation of the diffusion of the most important technological shocks and of the convergence or divergence processes in terms of productivity levels.

In order to establish the stylized facts of productivity growth, we smooth the annual productivity 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.

Figures 1 and 2 represent smoothed productivity growth, for labor productivity (*LP*) and total factor productivity (*TFP*), respectively, from 1890 to 2012 for the United States, the euro area, Japan, and the United Kingdom. Figures 3 and 4 represent the level of labor productivity per hour (*LP*) and total factor productivity (*TFP*) relative to the current U.S. level for the main economic areas, that is, the euro area, the United Kingdom, and Japan. And finally, Figure 5 represents the distance with the U.S. productivity (*LP* and *TFP*) level and breaks in this distance for these regions. The distance has been computed as the ratio $\frac{X-US}{X}$, where X denotes the productivity of a region X, and US the productivity of the U.S. Similar graphs have been plotted for other countries and are reported in Appendix 4.

We mainly distinguish four periods from 1890 to 2012 (see Figures 1 to 4):

1. From 1890 to WWI, productivity grew moderately and was characterized by a U.K. leadership and a catch-up by the other countries.
2. After the WWI slump, the interwar and WWII years were characterized by a heightening of the U.S. leadership, as it experienced an impressive big wave of productivity growth in the 1930s and 1940s identified by Gordon (1999, 2004), while other countries struggled with the Great Depression legacy and WWII.
3. After WWII, European countries and Japan benefited from the big wave experienced earlier in the United States.
4. Since 1995, the post-war convergence process has come to an end as U.S. productivity growth overtook that of Japan and other countries, although it has not returned to the pace observed in the 1930s or 1940s. Shorter and smaller than the first one, a second big wave appeared in the U.S. and, in a less explicit way, in the other areas.

We now explain the innovation diffusion processes (Section 3.1) before focusing more on productivity convergence across countries and the productivity catching-up process (Section 3.2).

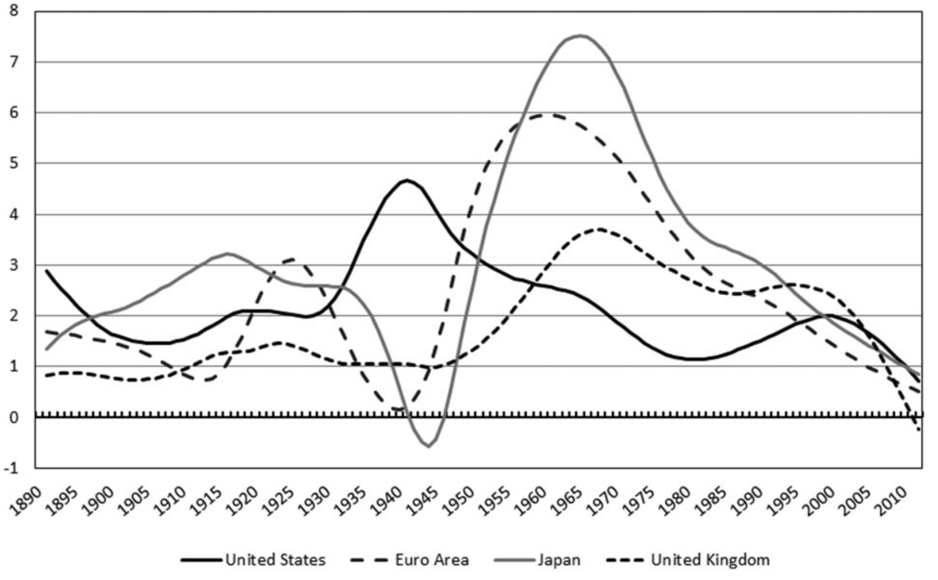

Figure 1. Smoothed (by Hodrick–Prescott Filtering[6]) Annual Growth of Labor Productivity per Hour (*LP*) in the United States, the Euro Area, Japan, and the United Kingdom, 1891 to 2012 (percent)

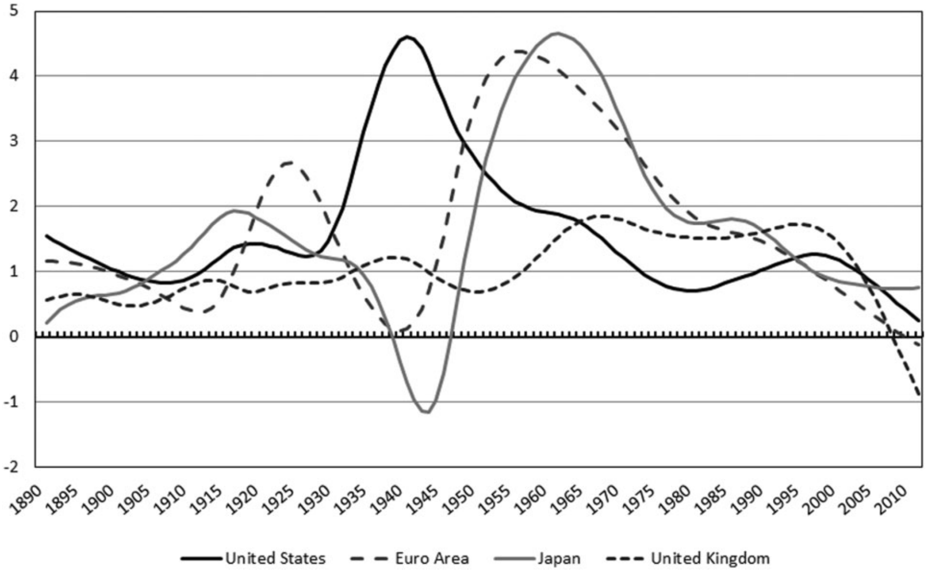

Figure 2. Smoothed (through Hodrick–Prescott Filtering) Annual Growth of Total Factor Productivity (*TFP*) in the United States, the Euro Area, Japan, and the United Kingdom, 1891 to 2012 (percent)

[6]We have chosen the HP filter parameter value: $\lambda = 500$.

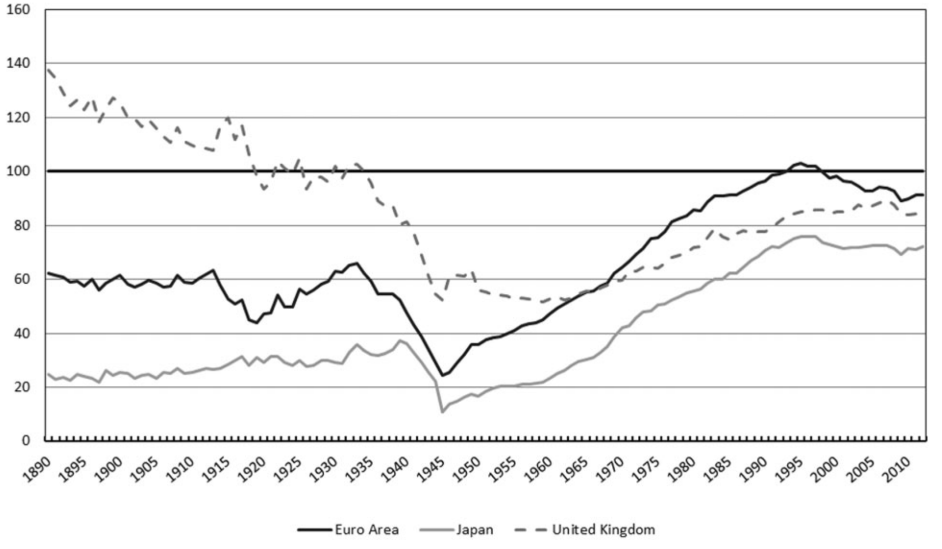

Figure 3. Level of Labor Productivity per Hour (*LP*) Relative to the Current U.S. Level in the Euro area, United Kingdom, and Japan, 1890 to 2012; $2005 PPP, U.S. level = 100

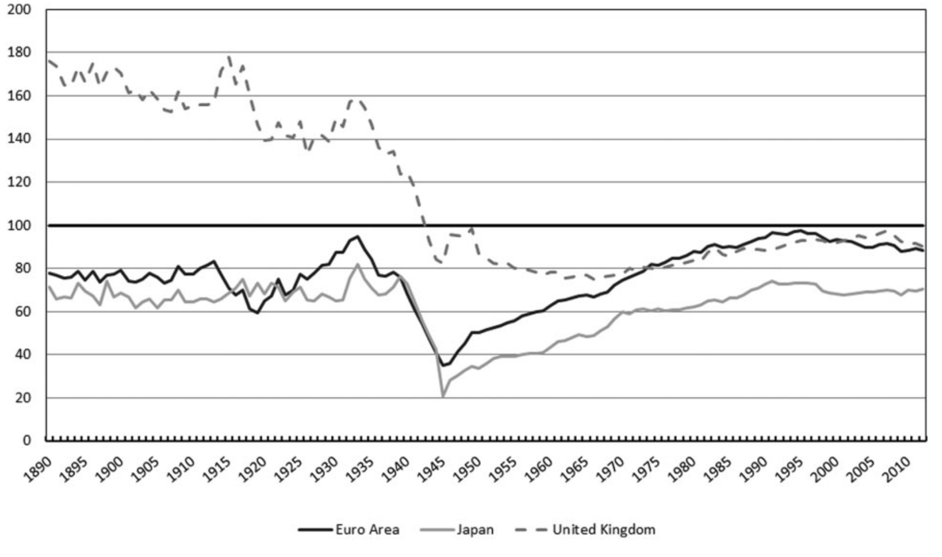

Figure 4. Level of Total Factor Productivity (*TFP*) Relative to the Current U.S. Level in the Euro Area, United Kingdom, and Japan, 1890 to 2012; $2005 PPP, U.S. level = 100

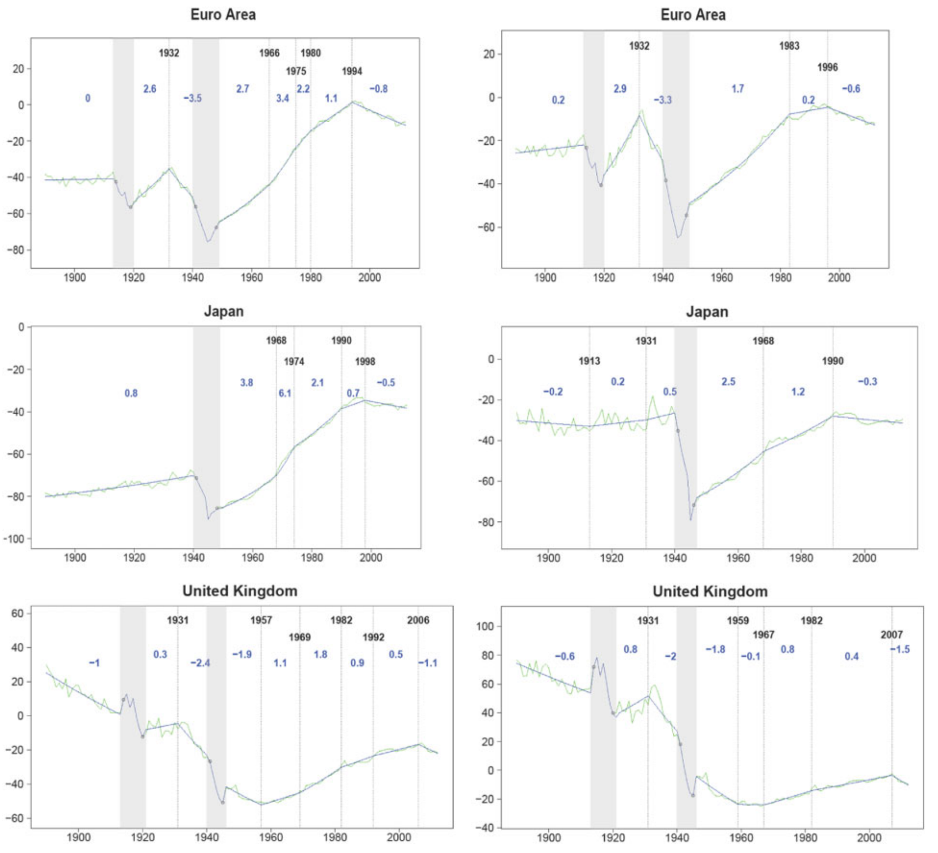

Figure 5. Distance with the U.S. in Productivity Level and Breaks in this Distance for Japan, United Kingdom, and the Euro Area, percent over the U.S. level; Left Column Corresponds to Labor Productivity, Right Column Corresponds to TFP

3.1. *Innovation Clusters and Their Diffusion in the Twentieth Century*

All countries experienced one big wave of productivity growth, but in a staggered manner: first the United States in the 1930s and 1940s, followed by the European countries and Japan after WWII. This wave was the strongest in the euro area and Japan, but from a much lower starting level than the United States (and even the United Kingdom for TFP). The U.S. relative productivity level made several leaps during each World War and its own big wave, giving rise to a convergence process after WWII that appeared to be completed in the 1990s for the euro area, but not yet for Japan or the United Kingdom.

Overall, the twentieth century saw major technological breakthroughs as the second industrial revolution spread across countries and sectors. The second industrial revolution was primarily technological, with the emergence of several General Purpose Technologies, that is, technologies spreading to most sectors, improving over time and spawning innovation (Bresnahan and Trajtenberg, 1995). Gordon (2000) distinguishes four major clusters of fields for this technological revolution:

- Electricity, in the form of light bulbs, reducing the cost of light (Nordhaus, 1996); and electric motors, providing a decentralized and flexible source of power.
- The internal combustion engine, which completely changed individual, collective and commercial transportation.
- Chemistry with petrochemistry and pharmaceuticals.
- Communication and information innovations with the telephone, radio, cinema.

However, the second industrial revolution was also a revolution in production organization and financial markets (Ferguson and Wascher, 2004). Production was reorganized according to Taylor (1911) scientific management principles and through assembly lines in large manufacturing firms (implemented, for example, for the Ford Model T in the Ford Motor Company in 1913).

Despite the impressive wave of technological innovations at the end of the nineteenth century, productivity accelerated significantly only in the interwar period in the United States and after WWII in the euro area. Before WWI, in the United States and the euro area, labor productivity growth was around 1.5 percent per year and TFP growth around 1 percent. It was much weaker in the productivity leader of that period (the United Kingdom) and much higher for the productivity laggard (Japan). After WWI, productivity growth impressively took off in the United States, with a short interruption during the Great Depression, reaching around 5 percent for both labor productivity and TFP after 1933. This surge was not as clear for other areas: the productivity trend was almost unchanged for the United Kingdom and Japan; and the euro area experienced a productivity rebound right after WWI but did not recover from the Great Depression. The full diffusion of the productivity gains of the second industrial revolution spread outside the United States only after WWII.

This slow diffusion followed the classic S-shape time path of new innovations (described in Jerome, 1934, for electricity) and hinged on the organizational changes needed to fully reap the benefits of these products. David (1990) analyzed the factors behind the diffusion lag of innovation: although the first practical design of a dynamo was presented in 1867, the conversion of industrial processes to electricity only took off after 1914–17 in the United States, as electrification required a fall in electricity prices and as a radical redesign of factory structures was necessary to benefit fully from this new technology.

The ICT technology shock had a sizeable impact on productivity growth in the U.S. from the 1980s onwards, with this impact increasing from the 1990s, as stressed by Jorgenson (2001), and afterward by numerous others including Jorgenson *et al.* (2006, 2008). ICTs had a favorable impact on productivity via two main channels (for a survey, see Oulton, 2012): (i) TFP gains largely driven by rapid technological progress in the different ICT-producing industries; (ii) and substitution effects linked to the accumulation of ICT capital (capital deepening), which itself results from the continuous and rapid improvements in the productive performance of ICT investments, leading to a sharp fall in the price of ICTs relative to other capital goods and labor.

A large body of literature (Schreyer, 2000; Colecchia and Schreyer, 2001; Pilat and Lee, 2001; Van Ark *et al.*, 2008; Timmer *et al.*, 2011) has shown that the level of diffusion of ICT differs greatly across the main industrialized countries, with the U.S. and the U.K. being the countries where diffusion appears to be the highest. Inklaar *et al.* (2005) showed that this gap in ICT diffusion was mainly located in service industries. Numerous studies provide alternative explanations for the ICT diffusion lag observed everywhere but in the U.K. and in the U.S. (see, for example, the studies quoted above). Cette and Lopez (2012) present a survey of this literature and show, through an econometric approach on country panel data, that this lag can be explained by differences in the average education level of the working age population and by higher labor and product market regulations.

An impressive slowdown in the impact of ICT on productivity seems to occur in the mid-2000s in the U.S. Gordon (2012, 2013) interprets this as a huge deceleration in progress in the semiconductor industry as predicted by Moore's law. He stresses that the wave of productivity growth corresponding to the main diffusion period of ICT is shorter and lower than that corresponding to the previous technological shock. Other studies, such as Aizcorbe *et al.* (2008) or Byrne *et al.* (2013), present the slowdown in the impact of ICT productivity as, at least partly, the result of an increase in price-cost mark-ups in the chip industry, or as a mismeasurement. Moreover, they do not exclude a second wave of productivity growth from new improvements in ICT. Other explanations of this slowdown are also plausible (for a survey, see Cette, 2014).

3.2. *Convergence Dynamics in the Twentieth Century*

Another driver of productivity growth has been convergence toward the productivity leader, that is, first the United Kingdom and then the United States (see Figures 3 and 4). The productivity convergence process may be explained by the fact that the follower countries copy the leader's best practices. Abramovitz (1986) lists several reasons why convergence may not take place or could remain unachieved, or why some countries benefit more than others from technological shocks (for example, the U.S. in the case of the ICT shock). The main reason appears, in the literature, to be institutional obstacles to the adoption of the leader's best practices and to the diffusion of the most efficient technologies (see Crafts and O'Rourke, 2013, for a broad survey).

The United States overtook the United Kingdom's labor productivity level at the turn of the century, just after WWI in our database and in the 1890s according to Broadberry and Irwin (2006). The divergence stems mainly from the purchasing power parity year reference and productivity per employee in their paper versus productivity per hour here. As early as the mid-nineteenth century, the United States had a large productivity lead in manufacturing, a sector which displayed a much greater degree of stationarity than the economy as a whole in terms of measures of productivity (Broadberry, 1993). However, the U.S. had a less favorable sectoral composition, with a greater share of labor in agriculture and was lagging in services (Broadberry, 1997; Broadberry and Irwin, 2006).

The origin of the U.S. productivity lead has been traced back to a sizeable internal market (in particular, Romer, 1996). However, when comparing the impact of long internal distances in the United States with the impact of borders in

Europe, market potential can only partly explain the U.S. leadership (Liu and Meissner, 2013). A greater emphasis is now placed on the more efficient exploitation of natural resources endowment in the United States, as cheap resources and resource-using machinery were substituted for scarce skilled labor (Ames and Rosenberg, 1968; Nelson and Wright, 1992).[7]

Before WWI, the United States, the euro area, and Japan were converging to the United Kingdom's level of productivity. WWI allowed the United States to make a major leap forward as production in countries experiencing war on their soil was profoundly disorganized by human or physical capital destructions and the changeover to a war economy. The euro area, and within this area, mainly France and Germany, experienced a downward break in their productivity levels, while the United States experienced an upward break. Compared to the pre-war path, Japan and the United Kingdom did not experience a break in their productivity level. The United States benefited from a positive demand shock due to war expenses in European countries, which led to an acceleration in the diffusion of innovation, in particular of electrification. The decrease in electricity prices, which occurred from 1914–17 onwards as regulated regional prices were lowered substantially, contributed to boost industrial electrification (David, 1990).

During the interwar years, after a rebound in European countries as production returned to normal, the United States made a second leap forward after the great depression as a wave of radically new products was introduced in the 1930s (Kleinknecht, 1987). In the immediate after-war period, the euro area started to converge toward the U.S. productivity level, as illustrated by the upward trend in relative productivity (Figure 5). However, the United States widened the gap after 1933, experiencing that year an upward break in the productivity trend, while European countries never recovered from the 1929 downward break (Figure 6). A downward break is indeed identified at the beginning of the 1930s for the euro area and the United Kingdom in their productivity trend relative to the United States (Figure 5). In Germany, labor productivity and total factor productivity were relatively dynamic during this interwar sub-period, with a convergence to the U.S. level not completely achieved for labor productivity but over-achieved for TFP during the Nazi period, due to the adoption of very high performance productive technologies (Ristuccia and Tooze, 2013). The productivity gap remained largely constant with respect to that of Japan during the interwar years, while it increased with the United Kingdom as barriers to competition allowed high-cost producers to remain in business (Broadberry and Crafts, 1990). During WWII, the impulse given by new products in the 1930s in the United States was reinforced by the positive demand shock from European countries and later by military R&D expenditures, while European countries and Japan were disorganized by war destructions. As a result, the United States experienced an upward break in its productivity level, while European countries and Japan saw a downward break.

[7]A similar explanation can be given for Australia's very high initial productivity level, which eroded as the economy expanded beyond the mining sector (Broadberry and Irwin, 2007; McLean, 2007).

Contrary to what could have been expected, convergence during the pre-WWII years of our sample did not apply to the manufacturing sector. Labor productivity in the U.S. manufacturing sector was twice as large as in the United Kingdom and Germany throughout most of the period and two and a half times as large after WWII.[8] Convergence during that period stemmed from sectoral reallocation, and in particular rural exodus,[9] as well as productivity growth in agriculture and services.

At the end of WWII, the productivity level relative to the U.S. was lower than just before WWII, both for labor productivity and for *TFP*, in all countries except Canada, where it was slightly higher (see Figures A4-1 and A4-2 in Appendix 4). In 1950, the relative (to the U.S. level) productivity level was particularly low (below 75 percent) in Japan and Europe, mainly for countries that had experienced conflict (for Spain, the civil war) on their soil (France, Germany, Italy, Spain, the Netherlands, and Finland).

After WWII, during a first sub-period, we observe that all countries except the United Kingdom, Canada, and Australia for *TFP*, experienced an impressive catch-up process to the U.S. productivity level (see Figure 5) (see Figures A4-1 and A4-2 in Appendix 4). This catch-up process can be attributed to a number of interrelated factors: a catch-up to the U.S. higher average education level of the working age population, the diffusion of technologies already widely used in the U.S., changes in the economic structure and, for example, a decline in the share of agriculture, which moved more into line with that of the United Kingdom and the United States.[10]

Using educational attainment data from Barro and Lee (2013), together with a classical Solow augmented framework and assuming an average rate-of-return to education of 7 percent on labor productivity,[11] we estimate that between 1950 and 1995, the share of human capital growth contribution in labor productivity growth dramatically increased from 5 percent (average from 1950 to 1974) to 25 percent (average from 1974 to 1995) in the euro area while it only increased from 21 to 27 percent in the U.S. At the end of WWII, the average population in the U.S. was almost twice as well educated as in the euro area (average duration of schooling in the total population of 15-year-olds and over was 8.4 years (0.39 for higher education) in the U.S. as compared to 4.9 years (0.06 for higher education) in the euro area). The gap was less considerable in 1995: 12.6 years (1.33 for higher education) for the U.S. and 9.1 years (0.5 for higher education) for the euro area.

[8]This is not however the case in Japan, whose manufacturing productivity relative to that of the U.S. increased over the period (Pilat, 1993); France's relative manufacturing productivity, on the contrary, decreased over the period (Dormois, 2006).

[9]The United Kingdom had a very small share of employment in agriculture in 1870 (22 percent) compared to other countries (50 percent in the United States and Germany), meaning that this share could diminish more rapidly in other countries during the period (Broadberry, 1997).

[10]Card and Freeman (2002) estimated that between 1960 and 1979, the impact on labor productivity of a change in the weight of employment in the agricultural sector amounted on average to roughly 0.5 percent each year in France, against 0.1 percent in the United Kingdom and the United States.

[11]This value of 7 percent for OECD countries is consistent with the value found in the literature (see Psacharopoulos (1994) for a review). The return to education may however be non-linear: it may be stronger when a country is far from the efficiency frontier and diminish as the country comes closer (Madsen, 2014).

The end of the catch-up process appears statistically significant and happened in the 1990s for the euro area[12] and Japan, and in the 2000s for the U.K. (see Figure 5).

In some cases, the productivity level observed at the end of the catch-up process was equivalent or even superior to that of the U.S.: in France, Germany, the Netherlands, Norway, and, for labor productivity, Italy and Sweden. It would be wrong to conclude from this that these countries were, at that time, as efficient as the U.S. in terms of the production process. In these countries, working time and/or the employment rate were lower than in the U.S. Several empirical studies find diminishing returns to hours worked and to the employment rate (see Bourlès and Cette (2005, 2007) for a survey and estimates) which means that at least part of the productivity performance of these countries was obtained from relatively low levels of hours worked or employment rate compared to that of the U.S. As regards labor productivity, in Norway, part of the performance also stemmed (and still stems), from a high level of the capital intensity, linked to the specific industry structure of this country (large share of capital intensive industry such as oil, fishing, and wood).

Conversely, the catch-up process stopped in Japan at a long distance from the U.S. productivity level, in 1998 for labor productivity and 1990 for TFP (see Figure 5). Recent analyses, for example Aghion and Howitt (2006) and Aghion *et al*. (2009), stress that low education levels and rigidities in labor and product markets have a large negative impact on productivity growth, the size of the impact depending on whether a country is far from or close to the technological frontier. We know that in the 1990s and even in the current period, market rigidities at an aggregate level are, among the countries of our dataset, highest in Japan and lowest in the United Kingdom and the United States, with the other countries in an intermediate situation. This could contribute to explaining the unfinished Japanese catch-up.

In the United Kingdom, the catch-up process started in the 1960s (1957 for *LP*, 1967 for *TFP*), after a relative decline, and ended in 2006 (see Figure 5). In Canada, we observe a permanent relative decline for TFP, and for labor productivity stability until the 1980s and a decline after that. In Australia, we observe for TFP a permanent relative decline, nevertheless from a high starting level. Boulhol and de Serres (2010) emphasize the role of remoteness from markets, which could cost as much as 10 percent of GDP for Australia or New Zealand. Moreover, inappropriate institutions (protective trade barriers, centralized industrial relations) could have weighed on economic convergence (Parham, 2002).

4. Productivity Breaks from 1890 to 2012

After the analysis of productivity growth waves, it is easier to review the breaks in productivity trends,[13] successively from 1890 to WWII (Section 4.1), and after WWII until 2012, which is the end of our dataset (Section 4.2).

[12]Boulhol and Turner (2008) also found a statistically significant break in the productivity catch-up process of Europe in the 1990s.

[13]Unless otherwise stated, every break date considered in this section is significant and robust to the choice of parameters in the computation of TFP (depreciation rate δ and elasticity of GDP with regard to capital α, see online Appendix 3).

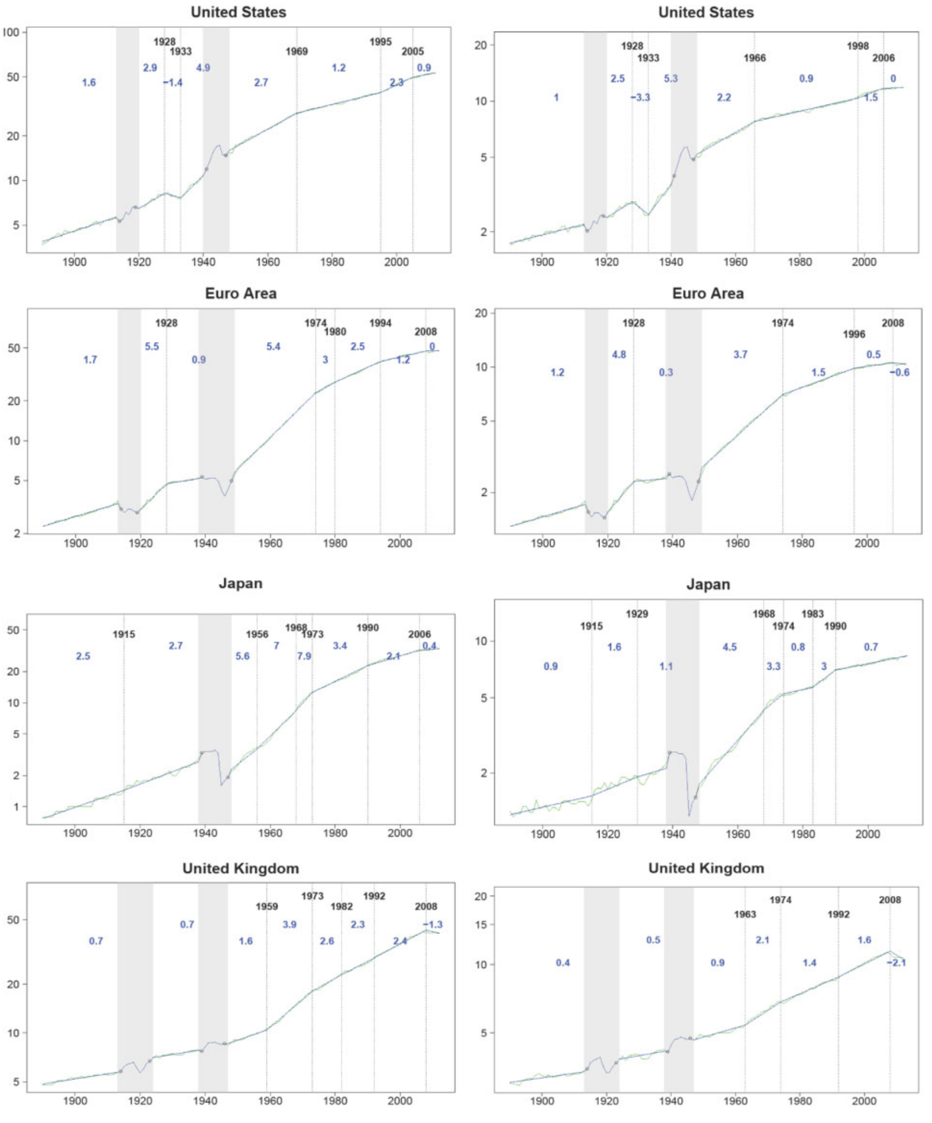

Figure 6. Productivity with Breaks; US$PPP of 2005 (log scale); Left Column is Labor Productivity per Hour, Right Column is TFP; Areas in Gray Represent War Periods as Calculated by Minimizing the AIC (see Appendix 2)

Figure 6 represents the productivity trends and breaks over the whole 1890–2012 period for the main regions (similar graphs are available in Appendix 4 for each of the 13 countries under review).

4.1. *Productivity Breaks from 1890 to WWII*

As explained previously, the period from the end of the nineteenth century to WWII was a period of major innovations as the second industrial revolution spread. It was also a period with very large productivity shocks related to the two World

Wars or the Great Depression, and of productivity leadership change as the United States took over from the United Kingdom. We distinguish four sub-periods during this period: from 1890 to WWI, WWI itself, the interwar years, and WWII itself.

4.1.1. Continuous Moderate Growth from 1890 to WWI

Despite major innovations, productivity growth during this period was slower than in the interwar years or the period after WWII, and most countries did not experience breaks. Among the main areas, the United Kingdom, the productivity leader at that time, experienced the slowest growth (0.7 percent for labor productivity and 0.4 percent for *TFP*), while Japan, the productivity laggard, experienced the fastest growth, mostly through capital accumulation (2.5 percent for labor productivity, but 0.9 percent for *TFP*). Productivity growth was similar in the United States and the euro area: around 1.6 percent for labor productivity and 1 percent for *TFP*.

In the euro area, the fastest labor productivity growth was experienced by Germany, in particular through the development of heavy industries, and the slowest in Spain, where industrialization was delayed by political disruption and protectionism (1906 tariff law). *TFP* growth was around 1.2 percent in most countries, apart from a dismal 0.5 percent in Spain.

4.1.2. The Interwar Years: High Volatility due to Innovation Diffusion, Catching-Up, and the Great Depression

Productivity accelerated almost everywhere after the war as innovation from the second industrial revolution spread, European countries recovered from war destruction, and the catching-up process fuelled growth. Productivity accelerated strongly in the United States and the euro area, with an impressive yearly growth rate of around 5 percent in labor productivity and *TFP*, but accelerated only slightly in Japan. The euro area, France and Germany, which were the most affected by the war, experienced the strongest rebound, around 6 percent both for labor productivity and *TFP*. The U.K. productivity trend was barely affected by the war.

The impact of the Great Depression differed in terms of intensity and duration: many countries experienced a downward break in productivity growth, but only a few experienced a subsequent upward break, while others faced a protracted slump. U.S. and Canadian productivity growth were strongly hit by the Great Depression and turned negative for 5 years, but recovered sharply afterwards as part of a cyclical rebound but also thanks to an impressive innovation cluster (Kleinknecht, 1987), a surge in privately-funded R&D, and well-chosen public infrastructure spending, in particular in the road system (Field, 2012). In the euro area, France, Germany, the Netherlands, and Spain experienced a downward break in productivity growth, which remained anemic or even negative for France, the Netherlands, and Spain throughout the 1930s.[14] As explained above, this downward break was smaller and productivity more dynamic after it in Germany than in other euro area countries and the U.S. In some countries (Japan, the

[14]For France, for this sub-period and the following one, our analysis is entirely consistent with that of Carré *et al.* (1972).

United Kingdom, Italy, Sweden, and Norway), the productivity trend was unaffected by the Great Depression as it hit less severely or durably in these countries than elsewhere.

4.1.3. WWII: New General Break in Productivity Trend and Level, with a New Leap Forward for the United States

WWII had a similar but more widespread impact than WWI as it centered on Europe but spread more strongly to Asia. It led to an upward break in level for the United States and Australia, which benefited from a positive demand shock from countries at war and massive public spending, helping to close the large output gap created by the Great Depression (Field, 2012). Conversely, in countries or areas experiencing war on their soil (the euro area, in particular Germany, and Japan), there was a downward break in their productivity level. The impact on the U.K. productivity level was limited as its war damages were much smaller than in Germany or Japan.

4.2. *Productivity Breaks after World War II*

We distinguish four sub-periods: from WWII to the first oil shock during the 1970s; from the first oil shock to the early 1990s, which corresponds to the end of the catch-up process for most of the countries; from the early 1990s to the start of the current Great Recession during the 2000s; and from the start of the Great Recession to 2012, the end of the period analyzed.

4.2.1. From WWII to the First Oil Shock: Productivity Slowdown in the Leading Country and Overall Productivity Convergence

During these 25 to 30 years, U.S. productivity growth was lower than during the years preceding WWII. This corresponds to the second part of the "One Big Wave" of productivity described by (Gordon, 1999, 2004). This productivity slowdown, which is observed both for labor productivity and for *TFP*, became so acute at the end of the 1960s that a large and highly statistically significant downward break[15] is detected. This slowdown has been often discussed in the literature. For example, Gordon (1999, 2004) interprets it as a gradual decline in the impact of the technological shock, mainly linked to the diffusion of electricity and of internal combustion engines and to the use of chemical products. Nevertheless, Bourlès and Cette (2007) have made the case that two-thirds of this slowdown in U.S. productivity can be accounted for by a rise in the employment rate and a smaller decline in working hours, with strong diminishing returns in both variables. It could also be linked to the rising engagement of the U.S. in the Vietnam War.

Five countries experienced productivity breaks before the 1970s: Canada, the United Kingdom, Spain, Finland, and Japan. In Canada, a downward break is detected only for *TFP*, in 1966. This break, which occurred at the same time as that of the U.S., can be explained by the intense commercial and technological relations between the two countries. However, this break is not detected when low values of

[15]Such a statistically significant U.S. downward productivity at the end of the 1960s was previously observed in other studies (e.g., Maury and Pluyaud, 2004).

capital depreciation are used to compute *TFP* and does not occur for *LP* (see Appendix 3). In the U.K., a large upward productivity break occurred in 1959 for labor productivity and in 1963 for *TFP*. From this upward break and the U.S. downward one, the relative (to the U.S.) decline in long-term productivity in the United Kingdom stopped and the catch-up process started. In the three other countries, a catch-up with the U.S. productivity level is observed during the whole sub-period.

During the 1970s, a downward productivity break occurred in most of the countries in the dataset: France, Germany, Italy, the Netherlands, Australia, Canada, Finland, and Sweden. As a result, a downward break also appeared in the euro area as a whole. These breaks can be attributed to the first oil shock. Except for Australia, Canada, and Sweden, the catching-up process to the U.S. productivity level was not interrupted by this downward break, but often slowed down.

Three countries in our dataset did not experience a downward productivity break during that period: the U.S., Spain, and Norway. But this downward break occurred in the second half of the 1960s for the U.S. and Spain (in addition, the use of high values for α and δ in the computation of TFP generates a break for Spain in 1972; see Appendix 3). And, in the U.S., this downward break may have been offset by a positive productivity shock from a broad deregulation process in particular industries, such as energy, communications, and transportation (Duernecker and Mand, 2013). Concerning Norway, 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 high-productivity activity.

4.2.2. From the First Oil Shock to the Early 1990s: Downward or Upward Productivity Growth Breaks and Productivity Convergence Still Ongoing

During this sub-period, productivity growth in the U.S. remained fairly stable at a low level since the 1960s, and the productivity catch-up process continued at least for a number of years in all other countries except, as mentioned before, Canada and Australia. Most of the countries in the dataset experienced a downward or upward productivity break during the 1980s and the early 1990s.

A productivity slowdown occurred in France, Germany, Spain, and Japan. As a result, such a downward down also appeared in the euro area as a whole, but only for labor productivity. In France, it occurred in 1985 and can be attributed to the implementation of a number of major policies explicitly aimed at reducing productivity growth, such as social tax cuts targeted at low-skilled employees. In Germany, it occurred in 1980 and 1990 and concerned both labor productivity and *TFP*. The slowdown of 1980 is not significant, while the slowdown in 1990 is naturally linked to the disruptions caused by the reunification, with East Germany being less efficient than West Germany. In these four countries, the productivity catch-up to the U.S. level was interrupted by these slowdowns. In the euro area as a whole, such a downward break was observed in 1980, but only for labor productivity, which means that capital intensity decreased, consistently with the decrease in labor costs caused by economic policies.

We observe upward productivity breaks in the United Kingdom, the Netherlands, Canada, Australia, and Sweden. In the United Kingdom, such a break occurred in 1992.[16] It was a very small one which can probably be attributed to the increased in the share of the highly productive financial industry. In the Netherlands, it occurred in 1983, one year after the Wassenaar Agreement between social partners, which gave a new boost to the Dutch economy (Visser and Hemerijck, 1998). The upward break occurred in the early 1990s in Canada, Australia, and Sweden, and can be ascribed to the widespread implementation of ambitious structural reforms, mainly concerning the State but also the product and labor markets (for Sweden, see Edquist, 2011).

4.2.3. From the Early 1990s to the Start of the Great Recession: Upward Productivity Growth Break in the U.S., Some Downward Ones Elsewhere, and the End of the Convergence Process

During this sub-period, we observe a sharp contrast in productivity behavior among countries: an upward break in the U.S. and a downward one in several other countries. Hence, the productivity catch-up to the U.S. productivity level was interrupted in all countries where it was not already the case and even became a relative decline in some of them. Previous studies have already found a statistically significant U.S. upward productivity break (Maury and Pluyaud, 2004; Bosquet and Fouquin, 2008) and an interruption in the European productivity catch-up process (Boulhol and Turner, 2008). An abundant literature has been devoted to the U.S. productivity upward break and to the contrast between this break and the productivity behavior in other countries.

In the U.S., this upward break was large, but insufficient to return to the rate of productivity growth observed before the breakdown of the 1960s. Jorgenson (2001) was probably the first to stress the role of ICT to explain the upward productivity break and to identify the role of ICT production and use. This productivity surge was the result of the acceleration in the ICT price decrease, in line with Moore's law.

The other countries did not benefit from the same positive impact of ICT on productivity growth because, except in the U.K., ICT diffusion was not as widespread as in the U.S. This lag in the diffusion of the ICT technological shock recalls the lag of several decades for the diffusion of the previous technological shock. This has been stressed in numerous studies (e.g., Van Ark *et al.*, 2008; Timmer *et al.*, 2011). Naturally, one important question is to ascertain the reason for the ICT diffusion lag in the non-U.S. countries. As mentioned above, several studies (Van Ark *et al.*, 2008; Aghion *et al.*, 2009; Cette and Lopez, 2012) stressed this point and showed that this ICT diffusion lag was due to the lower education level of the working age population and to higher rigidities on product and labor markets relative to the U.S. Indeed, even after the catch-up following WWII, differences in higher education attainment between the U.S. and other countries, especially the euro area, are still considerable (1.3 years for the U.S. in 1995 compared to around 0.5 in euro area countries). This situation, which still persists, leaves room for policy productivity improvement in numerous advanced countries.

[16]Such statistically significant productivity upward breaks in the early 1990 in Sweden and the U.K. had already been shown in the literature (e.g., Bosquet and Fouquin, 2008). In the U.K., an upward break is observed in 1987 when the depreciation rate is set at a higher level.

A downward productivity break occurred in this sub-period in France, Italy, the Netherlands, Spain, Australia, and Canada, and as a result in the euro area as a whole. It occurred in the mid-1990s in Italy, Spain, and the euro area as a whole, in 1995 in the Netherlands, and at the beginning of the 2000s in France, Australia, and Canada. In several countries such as the European ones, these downward productivity breaks can be largely explained by the implementation and the development of employment policies such as subsidized jobs and social tax cuts. In other countries, such as Spain, they also stemmed from the rapid development of the construction industry, which is characterized by a relatively low productivity level and low productivity growth.

4.2.4. From the Start of the Great Recession to 2012: Productivity Slowdown and no Resumption of Productivity Convergence

In most countries, a downward break occurred at the start of the Great Recession. At least part of these downward breaks in productivity may be due to the cyclical impact of the huge growth decrease during the crisis, since production factor adjustments are not instantaneous. A precise decomposition between cyclical and structural components of the productivity behavior from the Great Recession would require longer data and could only be carried out in a few years' time. We must also stress that part of the *TFP* growth decrease during the Great Recession could be due to capital mismeasurement. Our indicator assumes invariant capital mortality laws and we know that the capital scrapping behavior is related to the global economic cycle (see Bonleu *et al.*, 2013, for an analysis of this behavior in French firms). It means that *TFP* could, in fact, be more dynamic during the Great Recession than it appears to be from our data.

In the U.S., a large downward break occurred in the mid-2000s. After this break, productivity growth became even lower than the pace observed from the mid-1960s to the mid-1990s. As mentioned before, Gordon (2012, 2013) finds this slowdown to be the result of the decreasing impact of the ICT technological shock. This decreasing impact is, for example, characterized by an impressive slowdown in the ICT price decrease from the beginning of the 2000s, which would mean a huge deceleration of Moore's law itself and which seems consistent with the analysis of Pillai (2011). Aizcorbe *et al.* (2008), and more recently, Byrne *et al.* (2013) present this ICT price behavior as, at least partly, the result of an increase in price-cost markups in the chip industry, or as a mismeasurement: the U.S. Bureau of Labor Statistics (BLS) matched-model methodology may overestimate the development of chip prices as of 2001 (for a survey, see Cette, 2014).

A downward productivity break also occurred during the second part of the 2000s in Japan, the United Kingdom, France, Germany, Italy, the Netherlands, Finland, Sweden, and Norway, and in the euro area as a whole.[17] No productivity break occurred in Australia and Canada, but these two countries are characterized by a previous downward productivity break in the early 2000s.

[17]In France, the 2008 downward break is not significant, which is probably due to the existence of a downward break in 2000. For Italy, when a high value of δ is used, the 2008 breaks moved to 2000. As a result, with the same specification, the 2008 break for the euro area as a whole is not totally robust to the change in the depreciation rate.

Spain is a specific and interesting case: we observe there a huge upward productivity break in 2006. This can be explained by the implosion of the over-developed construction industry, which is characterized by a low relative productivity level.

5. Conclusion

Adopting a long-term view on productivity developments is crucial when studying decade-long phenomena such as innovation diffusion or convergence processes. It provides a precious analysis of the way innovation spreads to productivity within and across countries, highlighting the current ICT revolution diffusion and its prospects. The database we built for the 1890–2012 period for 13 countries, including major advanced countries, allows us to carry out this analysis.

Over the twentieth century, we observe "one big wave" of productivity growth linked to the second industrial revolution and a smaller and shorter ongoing one linked to the ICT revolution. The first big wave of productivity growth occurred long after the actual innovation that triggered it (internal combustion engine, electricity, chemistry, telephone, assembly lines, etc.) and spread across countries in a staggered way, first in the U.S. during the interwar years, then in the rest of the world after WWII. The productivity leader changed during the period, the leadership changing from an Australian and U.K. one to a U.S. one during the first part of the twentieth century and, for highly specific reasons, also a Norwegian, Dutch, and French one at least for some years at the end of the twentieth century. The convergence process has been erratic, disrupted by inappropriate institutions, technology shocks (second industrial revolution, ICT revolution), and financial crises as well as largely by wars, which led to major productivity level leaps, downwards for countries affected on their soil and upwards for other countries. Productivity trend breaks were detected following wars, financial crises (the Great Depression and the Great Recession), and supply shocks (the two oil shocks), but also major policy changes such as the implementation of structural reforms (Canada or Sweden in the 1990s). The upward break in the U.S. in the mid-1990s is confirmed, as well as the downward break in the euro area in the same period. A global downward break following the subprime crisis and in the mid-2000s in the U.S. is observed, casting doubt on the productivity consequences of the ICT revolution within a decade, although the long lag in the diffusion of the second industrial revolution shows that technology clusters may not yield all their benefits within a decade.

As far as comparisons are possible, these results are consistent with those of other analyses usually carried out on one or a limited number of countries and over shorter periods (see, for example, the survey of numerous analyses proposed by Crafts and O'Rourke, 2013). In the current period where advanced countries and particularly the euro area are suffer from a low growth outlook, it seems particularly appropriate to underline one result confirmed by our analysis: the large influence of institutions on productivity development. This means that structural reforms could significantly enhance productivity and growth in the euro area, where labor and product market regulations are significant and have a negative impact, for example on ICT diffusion.

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Supporting Information

Additional Supporting Information may be found in the online version of this article at the publisher's web-site:

Appendix 1: Data Appendix
Table A1-1: Initialization date (t_0) of the capital series (K)
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Graph A4-4: Level of total factor productivity (*TFP*) relative to the current US level in Euro Area countries 1890 to 2012—$ 2005 ppp—US level = 100
Graph A4-5: Productivity with breaks
B—For Euro Area Countries
Graph A4-6: Productivity with breaks
C—For Other Countries
Excel file containing data for TFP and LP