What role did education, equipment age and technology play in 20th century productivity growth?

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The 20th century was a period of exceptional growth, driven mainly by the increase in total factor productivity (TFP). Studying 17 OECD countries over the 1890-2013 period,[1] this Rue de la Banque *shows that the "one big wave" of productivity growth in the mid-20th century, as well as the ICT productivity wave, remain only partially explained when taking into account quality-adjusted factors such as education, equipment age and technology diffusion along with the stock of productive capital and hours worked. These results plead for a wider view on growth factors, encompassing changes in the production process, management techniques, financing practices, firm demography and factor allocation.*

Growth in the 20th century has been characterised by three stylised facts, which the growth literature has tried to explain over recent decades. First, the period starting with the second industrial revolution was a period of exceptional growth compared to the past history of mankind or even to the first industrial revolution. As far as we can rely on data from the distant past, world gross domestic product (GDP) per capita growth has averaged 1.5% per year from 1870 to 2000, compared with less than 0.1% during the pre-industrial era (1000-1760) and 0.3% during the first industrial revolution (1760-1870), (Maddison, 2001). Second, this take-off was uneven across countries, leading to a "Great divergence" (Galor, 2005) between emerging and advanced economies, and was staggered across advanced countries. Finally, GDP per capita has slowed markedly in advanced countries since the 1970s, leading commentators to question the durability of the 20th century's pace of growth (Gordon, 2012). GDP per capita in emerging countries has accelerated since the 1970s, but if global technological progress stalls, it will ultimately slow down as these

countries complete their catch-up process. These stylised facts lead to three questions: why did such a take-off occur at this stage of human history? Why was the take-off so heterogeneous? Will the take-off last? These questions have already been extensively addressed by the growth literature, which focuses both on the factors of growth and the convergence process.

One crucial factor in answering these questions is to quantify the contribution of traditional factors of growth (capital, labour) taking into account their quality but also, beyond this growth accounting exercise, to explore more deeply the role in long-term growth of General Purpose Technologies (GPTs), i.e. technologies that pervade many sectors, improve rapidly, and spawn further innovations. Growth accounting (Solow, 1957) was a first attempt to analyse the respective roles of production factors, failing however to explain the bulk of 20th century growth, which

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was attributed to total factor productivity (TFP), the residual of this decomposition. TFP improvements are attributed to technical change, which however remains largely a "black box" notion or a "Manna from the heaven", to use the expression from Hulten (2000). This is partly related to the difficulty in grasping the role of GPTs, due to their pervasiveness and their technological dynamism, which makes identifying and measuring their impact difficult (Bresnahan and Trajtenberg, 1995). Indeed, GPTs' contribution goes beyond factors included in the growth accounting approach such as capital deepening in GPT-related equipment and TFP improvement in GPT producing sectors. First, GPTs lead to fundamental changes in the production process of GPT-using industries. These changes may be badly accounted for in growth accounting exercises, for example if they require the accumulation of complementary organisational capital (Basu and Fernald, 2007). Second, GPTs may generate spillovers to seemingly far-away sectors (Helpman and Trajtenberg, 1998). Third, GPTs may have a long diffusion lag (see for instance David, 1990).
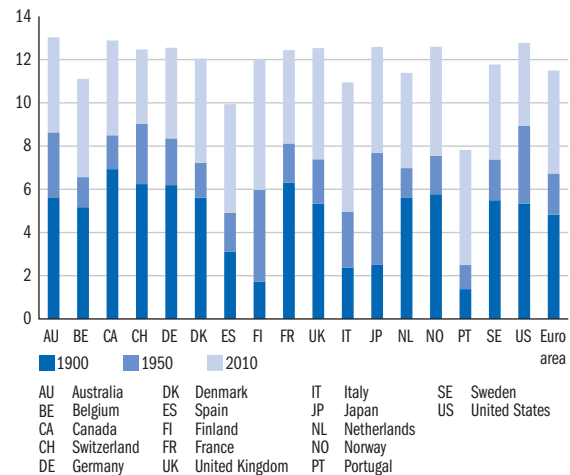
We have estimated the role of quality-adjusted production factors and technology diffusion in the GDP per capita growth of 17 OECD countries over the period 1890-2013. First, we have built a long-run dataset over a large number of countries, with data reconstituted in purchasing power parity and on the basis of, as much as possible, consistent assumptions. Second, we have adjusted production factors for quality, taking into account levels of education (see chart 1) and the age of the capital stock (see chart 2). Third, our main contribution is to estimate the impact of technology diffusion on TFP growth, focusing on two GPTs, electricity and Information and Communication Technologies (ICT), often considered as characteristic of different technology diffusion periods across the 20th century.[2]

A significant increase in education levels in the 20th century

Chart 1 shows that the average level of education was roughly the same for the euro area and the United States in 1900, whereas the latter had a more educated population by an average of 2.2 years in 1950. This is the result of the "high school movement" in the United States resulting in a large increase in secondary education attainment from 1910 to 1940, namely due to the building of new public schools. Hence, secondary education enrolment doubled between 1920 and 1930, while in Europe, in addition to being at a lower level, the increase was minimal. At the same time, there was not much difference in tertiary

C1 Educational attainment in 1900, 1950 and 2010
Average duration of schooling for the population aged over 15

(in years)

AU	Australia	DK Denmark	IT Italy	SE Sweden
BE	Belgium	ES Spain	JP Japan	US United States
CA	Canada	FI Finland	NL Netherlands	
CH	Switzerland	FR France	NO Norway	
DE	Germany	UK United Kingdom	PT Portugal	

Source: van Leeuwen and van Leeuwen-Li (2014).

education enrolment between the two regions according to data from Mitchell (1998a, 1998b). At the end of the period, the United States still had a significant advance over the euro area. This difference was mostly driven by differences in tertiary education which emerged during the 1950s along with mass investment in research during the Space Race.

## The average age of capital, an indicator of capital quality

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, although this relationship may not be stable through time. This simply translates the intuitive idea of a vintage effect: older capital should be less productive than newer capital, as suggested by Solow (1962).

The results of these calculations for equipment capital stock are presented in chart 2 for the United States, Japan, the United Kingdom and the euro area. The average age varies from 4 to 8 years depending on the period.

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2 *The contribution of these technologies is estimated through a 2SLS strategy to address endogeneity issues, using lagged distance-weighted technology diffusion by trade partners' countries as an instrumental variable. This identification strategy relies on the fact that trade is closely correlated to distance and is a major vector of technology diffusion.*

C2 **Average age of equipment capital**

(in years)
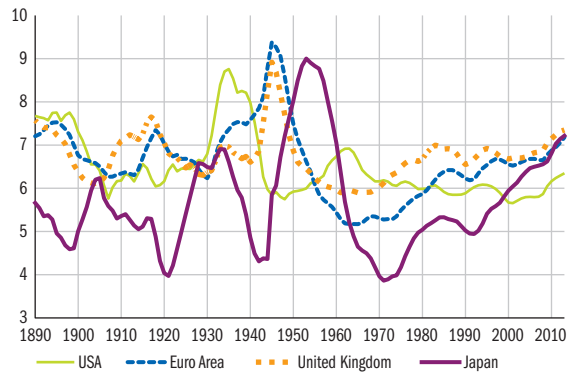
Source: Authors' calculations.
Note: The depreciation rate is assumed to be equal to 10%.

It increased strongly during the Great Depression in the United States, which weighed heavily on investment; it decreased significantly during World War II due to the war effort, and more modestly during 1995-2005, during the ICT wave, i.e. the period when ICT contributed the most to productivity growth in the United States, as new investment was needed to incorporate the new technology. In the euro area and the United Kingdom, it increased significantly during World War II as the conflict depressed investment and decreased in the post-war reconstruction period. It has pursued 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 counter-cyclical fluctuations can be observed.

A large contribution to growth from education, staggered across countries

Among factor quality considerations, education levels have posted the largest contribution to growth, while the age of capital has made a significant, although limited, contribution. Changes 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 accounted for 21% of TFP growth in the United States, 17% in the euro area, 25% in the United Kingdom and 26% in Japan. However, even if education (mainly) and the age of capital have a strong impact on productivity levels and growth, they do not explain the productivity waves observed during the 20th century. Interestingly, the "one big wave" (Gordon, 1999), the period from the 1940s to the 1960s when a burst of productivity occurred in the United States, is the one most affected by the exclusion of education and age of

capital: for the United States, the peak is reduced by 25% (see chart 3). Conversely, education and capital age barely contribute to explaining the ICT wave in the United States, as education reached a plateau and the age of capital only slightly decreased during the 1990s and increased when the financial crisis struck. In other areas, the contribution of education is lower than before, although it posted a significant contribution in the euro area and Japan, where the opening-up of college education to the masses was delayed compared to the United States. Equipment has aged since 1990 in Japan due to the banking crisis and since the 2000s in the euro area. Hence, the early opening up of education to the masses in the United States yielded a lasting contribution to productivity and partly explains the US advance. Indeed, the increase in the contribution of education occurs one period later, in the 1950s, in the other regions (euro area, the United Kingdom). In Japan, education made a significant contribution throughout the century due to the initial very low level of education. The age of capital makes a significant contribution mainly during the reconstruction period after World War II in the euro area and Japan, but otherwise its contribution is mostly pro-cyclical and hence limited on average in the long run. Summing up, quality-adjusted production factors explain less than half of labour productivity growth in the largest countries, with the exception of Japan, where capital deepening posted a very large contribution.

Technology diffusion leaves a significant proportion of productivity waves unexplained

To measure the diffusion of technology over the whole period, we have drawn on the CHAT database (Cross-country Historical Adoption of Technology) constructed by Comin and Hobijn (2009) and, in the more recent time period, on the work of Cette et al. (2015), which provides estimates of the stock of capital of three ICTs from 1950 to 2012 for 14 of our 17 study-countries. In the long run, according to our estimates, a 1% increase in the production of electricity per capita generates a growth in productivity of almost 0.1%, while a one standard deviation (0.049) increase in the ratio of ICT to GDP in value terms generates an increase of 7.4% in productivity.

Chart 3 plots the three waves from 1905 to 2010 for the United States for the growth rates of TFP, the residual including education, age of capital, electricity and ICT, TFP', which excludes the impact of education and age of capital and TFP", which also excludes the impact of electricity and ICT. We can see that the general evolution is still persistent, 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'. The ICT wave

C3 Filtered growth rate of different TFP measurements for the United States, 1905-2010

(in %)
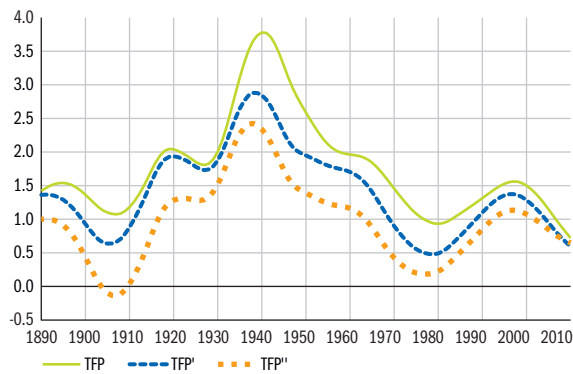
Source: Authors' calculations.
Note : TFP (total factor productivity) is the residual including education, age of capital, electricity and ICT (Information and Communication Technologies). TFP' excludes the impact of education and age of capital and TFP'' also excludes the impact of electricity and ICT.
The series have been computed using a HP filter with coefficient 500 (λ = 500) over the period 1890-2010 to address the issue of initial values.

is also significantly explained. Indeed, about 35% of the corresponding productivity wave is explained by education, age of capital and the inclusion of ICT diffusion in our estimates.

To sum up, the "one big wave" of productivity growth, as well as of the ICT productivity wave for the countries which experienced it, remains partly unexplained by quality-adjusted factors, although the early access of the masses to higher education explains to a certain extent the US advance over the other countries before World War II. Our main contribution is however the estimation of the impact of GPTs on long-term growth. Technology diffusion, as captured through our two GPTs, also contributes to explaining the US advance in the 1930s-1940s and ICT productivity waves but leaves between 0.6 and 1 point of yearly growth, as well as a large share of the two 20th century technology waves, unexplained (see chart 3). These results support both a significant lag in the diffusion of GPTs and a wider view on growth factors, encompassing changes in the production process, financing techniques, management practices, firm demography, factor allocation, etc.

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