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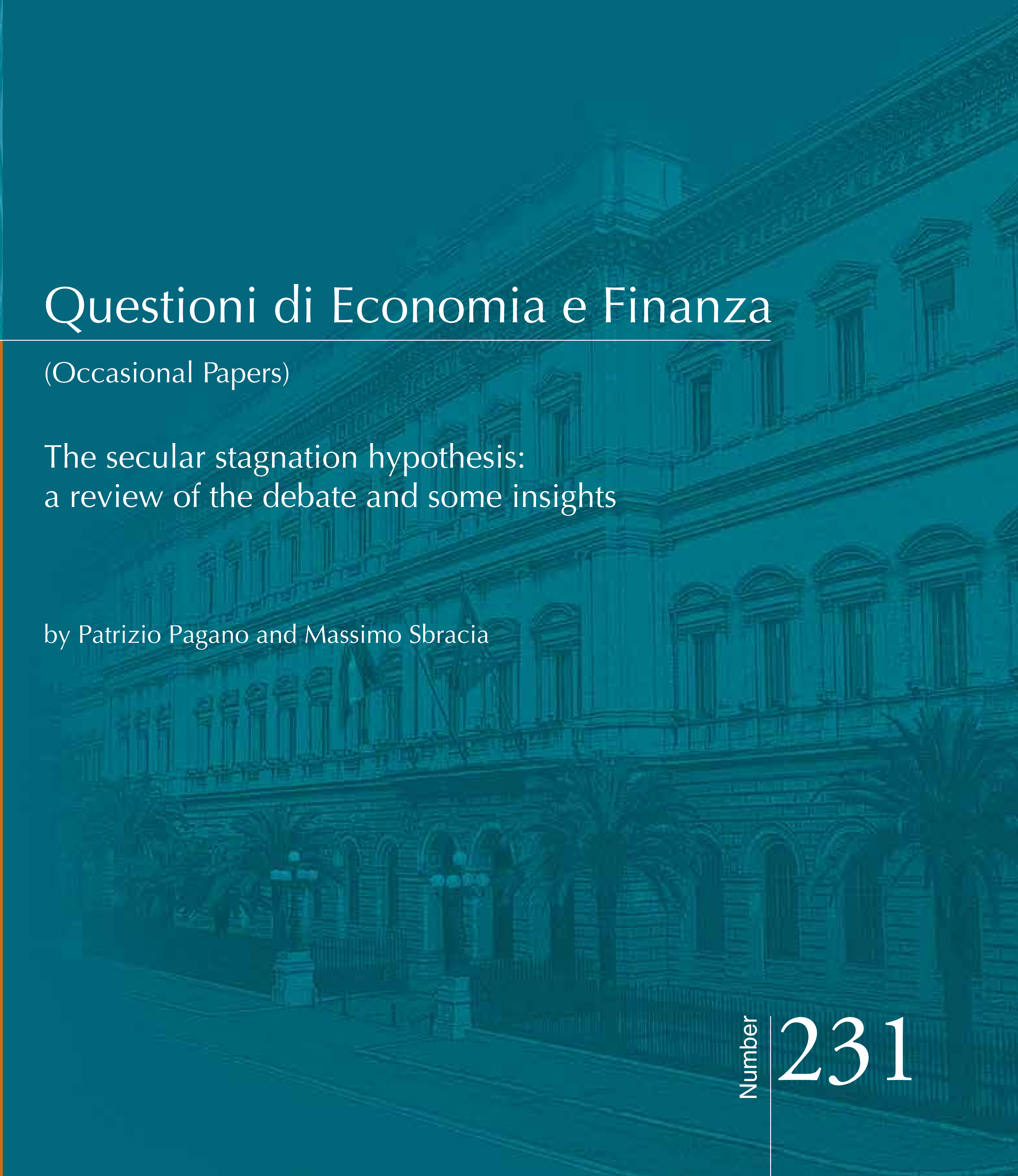

Questioni di Economia e Finanza

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**THE SECULAR STAGNATION HYPOTHESIS:
A REVIEW OF THE DEBATE AND SOME INSIGHTS***

by Patrizio Pagano[§] and Massimo Sbracia[§]

Abstract

Recent studies warn that the U.S. economy may return to a phase of secular stagnation. In the next 20 to 50 years, U.S. economic growth will be negatively affected by lower contributions of hours worked and education. But some studies also add that productivity could decelerate sharply and that GDP per capita, by focusing on the average household, neglects that income has already been stagnating in the last 30 years for the households in the bottom 99% of the income distribution. After reviewing recent long-run projections, we argue that similar warnings were issued in the past after all deep recessions. Interestingly, pessimistic predictions turned out to be wrong neither because they were built on erroneous theories or data, nor because they failed to predict the discovery of new technologies, but because they underestimated the potential of the technologies that already existed. These findings suggest that today we should not make the same mistake and undervalue the effects of the information technology. Finally, we discuss a number of issues that should be tackled by future research.

JEL Classification: O3, O4, O51, N1.

Keywords: secular stagnation, technological change, income inequality.

Contents

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1 Introduction

At the IMF Research Conference in November 2013, Lawrence Summers delivered a speech in which he suggested that *secular stagnation* might be "the defining issue of our age" (Summers, 2013). He argued that the natural real interest rate in the U.S. may have declined, reaching negative levels since at least the early 2000s, in the order of -2% or -3%. The fact that in this period actual long-term real rates have instead remained positive would explain why, despite the recurrent formation of bubbles in the financial and housing markets, capacity utilization has never been under any pressure, unemployment has not been remarkably low, and inflation has been entirely quiescent. In this situation, not only a rate hike by the Federal Reserve in the near term could turn out to be premature, but even zero nominal interest rates could inhibit current and future economic activity, holding the U.S. economy below its potential.

Following Summers' remarks, the issue of secular stagnation is now taking the center stage in both the research and the policy agenda (see, for example, the important volume recently edited by Teulings and Baldwin, 2014). As Eichengreen (2014) put it, however, secular stagnation is like the Rorschach inkblot test: it means different things to different people.

While Summers' argument focuses on the natural real interest rate and, ultimately, on aggregate demand (which is depressed by actual interest rates being higher than the natural rate), a second approach to this question rests on aggregate supply. In particular, a series of studies have recently hypothesized that potential growth in the U.S. may have come to a halt.[1] These studies recall that the world economy stagnated for many centuries until the Industrial Revolution and question the assumption that economic growth can persist forever, predicting a sharp deceleration of productivity and a return to stagnation. The focus of these studies is the United States, the country that has been identified with the world technology frontier since the early XX century.[2] In this paper, we review these recent studies as well as other existing projections, discussing their implications for both the future evolution of long-run economic growth in the U.S. and for the level of the natural interest rate

We start our investigation by examining the determinants of the *natural interest rate*. Barsky et al. (2014) show that cyclical factors related to the Great Recession of 2008-2009 and the subsequent weak recovery may have brought the natural interest rate down to negative values since 2009, close to the levels suggested by Summers. Abstracting from cyclical factors, however, it is unlikely that the natural interest rate will remain negative for a prolonged period of time: rising GDP per capita and prefer-

[1]See, for example, Byrne et al. (2013), Cowen (2011), Gordon (2012 and 2014), Lindsey (2013), and Vijg (2011).

[2]These studies also argue that other countries, especially the less developed, may still have room for "catch up growth", even in the case of a slowdown in the technology frontier.

ences for current vis-à-vis future consumption tend to keep the natural rate in positive territory. Nevertheless, a decline of the natural interest rate to low, albeit positive, levels in the long run seems to be a more concrete possibility. This would happen, in particular, in the case of a marked slowdown in GDP per capita.

To get some clues on the long-run prospects, we examine the *sources of U.S. GDP per capita growth* in the post-World War II period — which is equal to an average annual rate of 2.2% — and review existing projections about future growth rates. Gordon (2012 and 2014) predicts that the contribution of *total factor productivity* (TFP), the main source of U.S. economic expansion, will decline from 1.6 percentage points in 1950-2007 to just 1.0 points over the next 20 to 50 years. The reasons for this prediction are that the effects of ICT seem to have already peaked, that TFP has started to decelerate in the last ten years, and that no other major breakthrough is in sight. But GDP per capita will be negatively affected also by other *transitory factors* that are expected to slow down, especially the total number of hours worked and the accumulation of skills. The contribution of these factors, equal to 0.5 percentage points in the post-war period, could become nil in the period until 2060, as a result of the retirement of baby boomers, the approaching of a plateau in the years of schooling, and the rising relative cost of higher education. Overall, the lower contributions of TFP and transitory factors imply that the growth of GDP per capita will halve, increasing at a rate of 1.1%. In the case of log preferences for consumption, this would translate into a 1.1 percentage point decline in the natural interest rate.

This gloomy prediction seems to be broadly confirmed by other projections. In particular, the fading contribution of the transitory factors is in line with the most recent forecasts based on the findings of Jorgenson et al. (2005) and the OECD (2014a). Regarding TFP, the OECD seems to endorse a sharp deceleration, although at a later stage (the period 2030-2060). Annual TFP growth of just around 1% is also consistent with recent models that split TFP into research intensity (i.e. the share of workers employed in research and development) and a size effect (the increase of the labor force that, in the long-run, is equal to that of the population).[3] In these models, a deceleration of TFP is the result of lower *population* growth, which implies a lower growth in the number of inventors.

Another important issue concerns *income inequality.* The analysis of GDP per capita, in fact, focuses implicitly on the *average* household. However, the recent strong rise of inequality has seen the share of total income received by households in the top 1% of the income distribution increase sharply, while income has been stagnating for more than 30 years for the remaining 99% of the U.S. population. Income inequality is also relevant for the natural interest rate, due to the higher propensity to save of

[3] See, in particular, Kremer (1993), Jones (1995a and 2002), and Kortum (1997). In these models, a higher population growth (size effect) translates into a higher growth rate of potential inventors and, in turn, a higher growth of TFP.

households in the upper percentiles of the income distribution: for a given average income, a more unequal distribution implies higher saving and lower interest rates. If inequality keeps growing at the same speed as it has in the last three decades, the income of the households in the bottom 99% of the distribution will grow at an annual rate that is 0.5 percentage points lower than the rate recorded for the entire U.S. population. Therefore, if the projections of GDP per capita growth of 1.1% are confirmed, these households' income will increase at a rate of just 0.6%.

Our review stresses that the most important factors for predicting long-term economic growth as well as the natural interest rate are *TFP*, *population* (which also contributes to TFP), *human capital* and *income inequality*. We then examine these factors from a broader historical perspective. The debate on secular stagnation is, in fact, a *cyclical question* that has been raised after all deep and prolonged recession. Revisiting the data and theories considered in the past helps us to understand, with the benefit of hindsight, the reasons why pessimistic predictions turned out to be wrong.

In retrospect, it emerges that pessimistic predictions were wrong neither because they built on erroneous theories or data, nor because they failed to predict new technologies, but because they underestimated the potential of the technologies *that already existed*. This analysis also suggests that pessimism about ICT may be unwarranted: its diffusion among U.S. households and businesses has quite closely matched that of electricity in the early XX century. Moreover, current research in the ICT sector is turning to the development of consumption devices, resembling the shift towards home appliances that occurred in the 1920s and 1930s and that anticipated the economic boom observed after World War II.

Historical experience also suggests a number of issues that should be tackled by future research. First, the key question concerning TFP is whether there are *diminishing returns on research*; that is, whether making progress becomes increasingly difficult as technology advances. The fact that, historically, the number of patents granted could scarcely keep pace with population growth has often been interpreted as evidence of diminishing returns (see, for example, Merton, 1935, or Griliches, 1990). This is, however, still a very open issue. *The long-run stability of the growth rate of U.S. GDP per capita since 1870 does not allow us to rule out that technological progress has instead a "fractal quality"*. In other words, it may well be that the probability that TFP increases does not depend on its level. Interestingly, the Pareto distribution, which is often used to describe productivities in the cross-section of firms, has exactly this property. We suggest, then, that the properties of the distribution of productivities in the time series and the cross-section of firms should be analyzed jointly.

Second, the relevant population for TFP growth, i.e. the people who can push the technology frontier outward, no longer coincides with the U.S. labor force, as suggested by many indicators (such as the rise in the share of U.S. patents granted to foreign residents). It is worth exploring, then, *the extent to which future TFP growth is likely* *to benefit from the integration of emerging countries into the global economy.*

Third, the evolution of human capital, usually proxied by the average number of years of schooling and workers' experience, is apparently more worrisome. In the short run, the increasing relative cost of higher education is making it less affordable. In the longer run, its accumulation, as measured in growth models, is bounded from above: work experience is limited by the retirement age, years of schooling by the fact that, well before the retirement age, students must leave school to repay education costs. Of these two problems, rising education costs could be effectively addressed by a variety of policies (like those that are currently being considered by the U.S. government), but also by private initiatives, such as the recent proliferation of Internet-based educational resources. One issue that we discuss and suggest for future research is *whether human capital can grow even if the average years of schooling and work experience remain constant.* In particular, human capital could be accumulated by *raising the quality of education (intensive margin) as well as the varieties of knowledge (extensive margin).* If this were true, human capital could keep contributing to economic growth over and above the mere number of years of schooling and work experience.

Fourth, the rise in the skill premium has been acknowledged as a key determinant of the recent increase in income inequality. Although the price mechanism can be a powerful force for promoting equality, the adjustment of demand and, especially, supply of the relevant skills can take many decades. Before the full adjustment takes place, relative wage differentials can become very wide, fuelling large and persistent income inequalities, which, nonetheless, start declining at some point. Economic history shows, for example, that technological progress has been accompanied by repeated reversals in the demand for skilled workers. The direction of technical change, then, can be shaped by relative prices, which determine the profit incentives to innovate and the amount of research activity directed towards different factors of production (Acemoglu, 1998 and 2002). Because both market forces and public policies can affect wage differentials, possibly giving rise to long *"inequality cycles"*, *predicting income inequality in the long run is a tough challenge and simple extrapolation from recent trends may turn out to be severely misleading.*

The rest of the paper is organized as follows. Section 2 revisits the determinants of the natural interest rate. In Section 3, we review the sources of U.S. GDP per capita in the post-war period and discuss existing projections about their future evolution. Since it emerges that the most important source of U.S. economic growth is TFP, a variable whose ultimate determinants have not been spelled out, Section 4 briefly reviews models that explain its growth and discusses their implications. Section 5 tackles the issue of income inequality. Section 6 examines the factors that emerged as the most important for long-term economic growth from a broader historical perspective. Section 7 concludes.

2 Determinants of the natural interest rate

The natural real interest rate (NRIR) was defined by Wicksell (1898) as the rate that "is neutral in respect to commodity prices, and tends neither to raise nor to lower them". Since then, various definitions have appeared in the literature.

In new Keynesian models, it is the real rate of return required to make output equal to its potential level, that is the level consistent with flexible prices and wages and constant markups in the markets for goods and labor (Woodford, 2003). While this definition is theoretically appealing, its usefulness for the practice of monetary policy faces the key hurdle that the NRIR is not directly observable. In addition, the NRIR fluctuates over time in response to a variety of shocks to preferences and technology, making it more difficult to assess its precise value. Moreover, setting the policy interest rate to make the real rate equal to the NRIR may be impossible during deep recessions, because of the bound that prevents nominal interest rates from dipping below zero. Despite these considerations, the NRIR remains an important reference point for monetary policy, whose estimate is worth attempting.

Barsky et al. (2014) use a dynamic stochastic general equilibrium model in order to estimate the NRIR that would prevail in an economy with neither nominal rigidities nor shocks to prices and wage markups.[4] Their results show that the NRIR follows a highly procyclical pattern, with very pronounced swings (fig. 1). Perhaps surprisingly, it does not display a substantially larger drop during the Great Recession than in the previous two downturns. However, in stark contrast with earlier episodes, it has remained persistently negative even during the recovery. In this model, this result is largely due to the strong increase in precautionary saving induced by a negative and extremely persistent shock to the risk premium in the Euler equation. This shock is necessary in the model to explain both the Great Recession and the subsequent weak recovery.

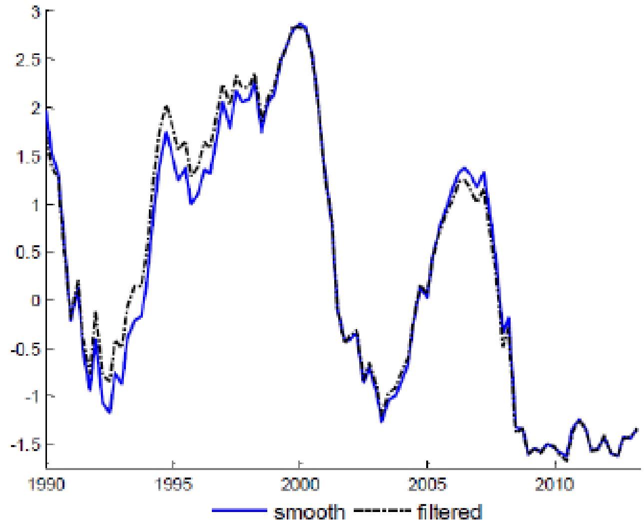
Thus, the NRIR may have turned negative since the Great Recession. The key question, however, is whether it could remain negative for a much more extended time period, i.e. whether its low level could reflect persistent structural problems rather than cyclical factors.[5]

In textbook models of economic growth, the NRIR is the real interest rate in a

[4] The model includes price and wage stickiness, backward-looking components in wage and price setting, habit formation, non-separable utility in consumption and leisure, as well as investment subject to adjustment costs. Policy-makers are assumed to respond to current, expected and lagged inflation as well as to deviations of GDP from its linear trend.

[5] We neglect the effects on the natural interest rate of higher financial and trade openness. For instance, a strong downward pressure on the natural interest rate in the U.S. may have been triggered by a boom in the global demand for safe assets (Caballero and Farhi, 2014) or by investment choices of foreign countries regarding the level of exchange rate reserves (Cova, Pagano and Pisani, 2014).

Figure 1: Estimates of the natural interest rate (1)



(1) One-sided (filtered) and two-sided (smoothed) estimate of the natural rate; percentages, quarterly data, from 1990-Q1 to 2013-Q2. Source: Barsky et al. (2014).

balanced-growth equilibrium, that is a long-run equilibrium in which all the variables grow at a constant rate. In the basic Ramsey model with exogenous technological progress, the real interest rate is determined by the growth rate of total factor productivity (TFP) and intertemporal preferences:

$$r = \rho + \theta x \ , \tag{1}$$

where r is the equilibrium real interest rate, ρ the discount factor (households' degree of impatience), x the exogenous rate of TFP growth, and $1/\theta$ the intertemporal elasticity of substitution (see, for example, Barro and Sala-i-Martin, 1995).

A decline in TFP growth (i.e. in x) or an increased willingness to save (corresponding to a reduction in ρ or θ) raise the detrended level of the capital stock in the balanced-growth equilibrium. Equation (1) suggests that these shocks lower the marginal product of capital and reduce the equilibrium interest rate. The intuition is that if households decide to consume less today and raise their savings in order to consume more tomorrow, then a lower interest rate is required to equate the higher saving with higher investment.

Given that the discount rate is assumed to be positive, equation (1) also shows that in the long run the NRIR can be negative only if TFP growth becomes negative and by a sufficiently large extent to more than offset the positive rate of intertemporal substitution.

A temporarily negative equilibrium interest rate could also result if, for any reason, the economy has accumulated "too much" capital stock. In this case, because there are diminishing returns on capital accumulation, the real interest rate — which is the marginal productivity of capital net of depreciation — could become negative.[6] The standard Ramsey model, however, precludes the possibility of this occurring in the long run because, in the balanced-growth equilibrium, the interest rate must exceed the growth rate of the capital stock. In particular, it must be $r \geq x + n$, where n is the growth rate of the population.[7]

The possibility of accumulating an "excessively large" capital stock, instead, is not precluded in overlapping generations models. In particular, in a celebrated article, Diamond (1965) shows that, with overlapping generations, a competitive economy can reach a balanced-growth equilibrium in which there is "too much" capital. In this case, the economy is dynamically inefficient and a Pareto improvement can be achieved by inducing all the generations to consume more and save less when they are young.

One must then investigate the possibility that the interest rate is negative because the economy has accumulated too much capital stock. In the Appendix, we spell out the details of a growth model in which we explore this possibility. In particular, we consider a model in which agents have finite lifetimes and, following Blanchard (1985), we assume that labor productivity (and, therefore, also the real wage) declines with age at a rate ω (an hypothesis that also reflects the fact that, after retiring, people receive pensions that are lower than their previous wages). This assumption reduces the NRIR. In fact, anticipating that there will be less income in the future, people want to save more, thereby lowering the interest rate. Because the effect of a steeper decline in wages is the same as that of a lower discount rate ρ, it can be shown that:

$$r \geq \rho + \theta x - \omega \ . \tag{2}$$

Equation (2) implies that, in theory, r could be negative if ω is sufficiently large. However, as shown in the Appendix, the value that this parameter must take in order to obtain negative interest rates seems quite implausible.[8]

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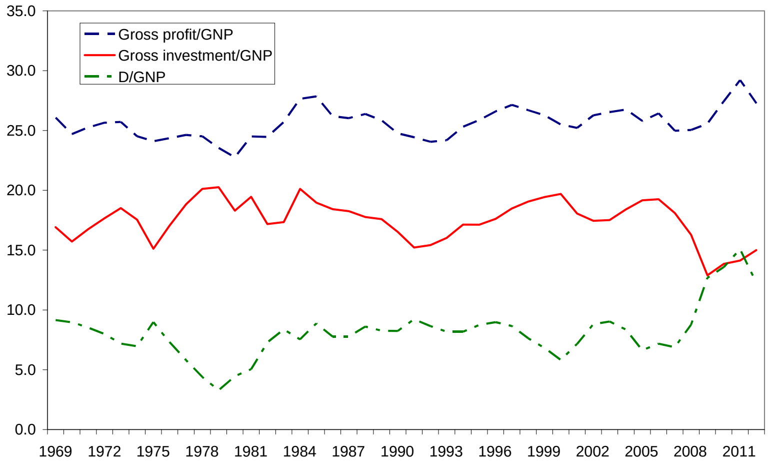
[6] An excess of capital stock could be the result of a shock such as a sudden decline of the population (due, for example, to an epidemic or a mass migration), which would determine too much capital per capita, or of erroneous expectations (over-optimism) that lead to an excessive accumulation of capital, which is then reversed as soon as agents become aware of the mistake.

[7] The real interest rate is equal to the sum of the growth rate of the population and the growth rate of productivity when the capital stock is at a level that maximizes consumption, the so-called "golden rule".

[8] In a recent paper, Eggertsson and Mehrotra (2014) build a model in which a deleveraging shock results in a persistent decline in the real interest rate. Their framework, which nests an overlapping generations setting into an otherwise standard New Keynesian model, features three types of agents: the young, who consume what they borrow, subject to a binding constraint; the middle aged, who earn the highest income, lend to the young, and save for old age; and the old, who consume their savings. A permanent fall in the borrowing limit — which represents a deleveraging shock — diminishes the demand for savings by the young, reducing the real interest rate. This decline, however, is persistent, because when the young become middle aged, they have less debt to repay and the resulting excess saving reduces the interest rate further, possibly triggering negative values, before the economy returns to a new steady-state equilibrium with a positive interest rate.

Figure 2: Gross profit and investment in the United States (1)



(1) "D/GNP" is the difference between gross profit and gross investment as a share of GNP; percentages, annual data. Source: Bureau of Economic Analysis.

Moreover, Abel et al. (1989) prove that in a competitive economy that accumulates excess capital stock, the rate of investment must be larger than the return on capital. Data for gross capital income and gross investment, available for the period 1969-2012, show, instead, that profits have been constantly higher than investments, and especially so in the last four years (fig. 2). This finding confirms that, abstracting from cyclical factors, a negative NRIR in the long run is unlikely.

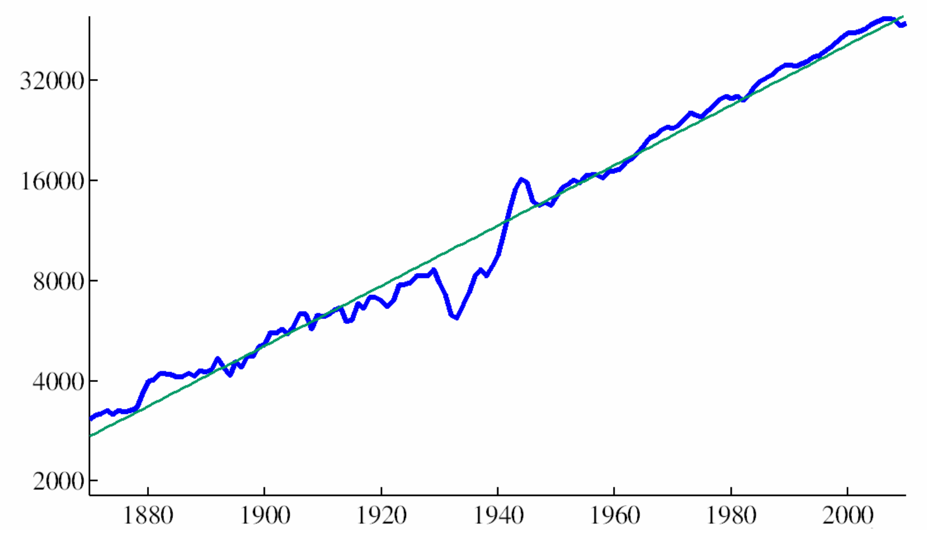
While a negative equilibrium interest rate for a prolonged period of time is unlikely, a decline to a very low, albeit positive, level seems to be a more concrete possibility. This would happen, in particular, following a strong slowdown in long-run economic growth. This possibility is analyzed in the next sections.

3 Sources of post-war U.S. growth

The growth rate of U.S. real GDP per capita has been very stable since the end of the XIX century (fig. 3). This apparent lack of persistent changes underlies the view that the U.S. economy is on a long-run balanced-growth path — a view supported by a number of stylized facts, such as the absence of trends in the capital-output ratio, emphasized by Kaldor (1961). This finding has also been used to argue in favor of exogenous growth models and against more recent endogenous growth models (Jones, 1995b).[9] Therefore, it makes sense to start our analysis by considering the implications

[9] Jones (1995b) gave the following example (suggested by David Weil, who, in turn, credits Lawrence Summers). An economist living in the year 1929, who fits a simple linear trend to the natural log of GDP per capita of the United States from 1880 to 1929 in an attempt to forecast current GDP per

Figure 3: U.S. GDP growth per capita: 1870-2010 (1)



(1) 2009 dollars; log scale. Sources: Bureau of Economic Analysis, Maddison (2008), Fernald and Jones (2014).

of a standard exogenous growth model, while a discussion of its limitations and some insights from alternative models are deferred to Section 4.

Assume that total output produced at time t, Y_t, is given by

$$Y_t = A_t^{\sigma} \cdot K_t^{\alpha} \cdot H_t^{1-\alpha} \ , \tag{3}$$

where A_t is TFP, σ is a positive parameter, K_t is physical capital, $\alpha \in (0,1)$ is the share of physical capital in value added, and H_t is the stock of human capital. The last variable has the following standard expression:

$$H_t = L_t h_t \ , \quad \text{with } h_t = \exp\left(\theta s_t\right) \ , \tag{4}$$

where L_t is the total number of hours worked, h_t is human capital per hour worked, s_t is the amount of time spent accumulating human capital (usually proxied by the average number of years of schooling and workers' experience), and $\theta > 0$ is the Mincerian return to education. From (3), we can write GDP per capita as:

$$\frac{Y_t}{P_t} = \frac{L_t}{P_t} \cdot A_t^{\sigma/(1-\alpha)} \cdot \left(\frac{K_t}{Y_t}\right)^{\alpha/(1-\alpha)} \cdot h_t \ , \tag{5}$$

where P_t is total population.

Using (5), the growth rate of GDP per capita can decomposed into the growth rates of its four main components: the *employment ratio* (hours worked over total

capita would make a remarkably precise prediction. At the end of the 1980s, the forecast would fall short by less than 5%.

population), *total factor productivity*, the *capital-output ratio*, and *human capital per hour worked.* A quantification for the period 1950-2007 is reported in equation (6) using data gathered by Fernald and Jones (2014); in this equation, we denote the growth rates of GDP per capita ($y_t = Y_t/P_t$), the employment ratio ($e_t = L_t/P_t$), TFP (A_t), capital output ($k_t = K_t/Y_t$), and human capital per hour worked (h_t) with, respectively, $\dot{y}$, $\dot{e}$, $\dot{a}$, $\dot{k}$, and $\dot{h}$:

$$\underset{(100\%)}{\overset{\dot{y}}{2.2\%}} = \underset{(6\%)}{\overset{\dot{e}}{0.1}} + \underset{(74\%)}{\overset{\frac{\sigma}{1-\alpha}\dot{a}}{1.6}} + \underset{(0\%)}{\overset{\frac{\alpha}{1-\alpha}\dot{k}}{0.0}} + \underset{(19\%)}{\overset{\dot{h}}{0.4}} \,. \tag{6}$$

Equation (6) shows that, between 1950 and 2007, GDP per capita grew at an annual rate of 2.2%. The exogenous growth rate of TFP has been by far the most important factor, increasing at a rate of 1.6% per year and explaining about 75% of the U.S. economic development in the post-war period.[10] Human capital, measured by the years of schooling and workers' experience, contributed almost 20%, growing at an annual rate of 0.4%. The contribution of the employment ratio was small (6%), as this variable grew at a rate of just 0.1% per year. Physical capital increased at the same rate as output, hence its contribution to the growth of GDP per capita has been nil.[11]

In the following section, we review existing projections about these four determinants of the growth rate of GDP per capita.

3.1 Total factor productivity

In two recent papers, Gordon (2012 and 2014) warned about a possible decline in the growth rate of TFP. Taking a very long-run perspective, he recalls that the Industrial Revolution was preceded by several centuries of stagnation, in which the growth rates of GDP per capita and of TFP were almost nil. In particular, Gordon (2012) focuses on GDP growth per capita in the *frontier economy*, which is identified with the U.K. from 1300 to 1906, and with the U.S. thereafter. Noting that growth almost stagnated from 1300 to about 1750, at about 0.2% per year, he then identifies three key phases

[10] The parameter α is calibrated at 0.32. An estimate of σ is not needed, since the contribution of $\sigma\dot{a}/(1-\alpha)$ is obtained as a residual.

[11] An alternative decomposition of output per capita considers *capital per worker* instead of the *capital-output ratio* (i.e. $y_t = e_t \cdot A_t \cdot (K_t/L_t)^{\alpha} \cdot h_t^{1-\alpha}$). Given that capital per worker increased significantly between 1950 and 2007, while the capital-output ratio remained broadly constant, this alternative decomposition suggests a somewhat smaller role for productivity and human capital. Although any growth accounting exercise is arbitrary, we prefer the one reported in equation (5), because it focuses more closely on the sources of economic growth that, in these models, are supposed to be "autonomous", i.e. productivity and human capital. In endogenous growth frameworks such as the AK-model, instead, physical capital is also an autonomous source of economic growth. See also Section 4.

of the Industrial Revolution:[12]

- In the first phase, the annual growth rate of GDP per capita gradually rose from 0.2% (before the year 1750) to almost 1% at the end of the XIX century. In this period, the most important innovations were the steam engine and the railroads, which were developed between 1750 and 1830, although their economic effects peaked after about 150 years.

- In the second phase, GDP growth per capita rose up to a record-high annual rate of 2.5% during the 1960s. The main inventions characterizing this phase were the internal combustion engine and electricity. They were developed between 1870 and 1900, but it took about 100 years before their full effects fed through to the economy.

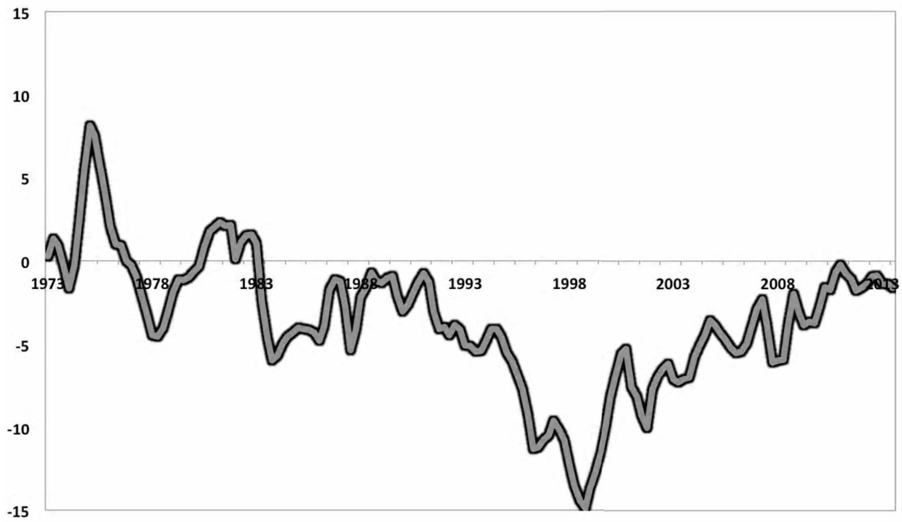
- The third phase took off with the invention of the computer and the Internet revolution, from 1960 onwards. Their impact on TFP peaked in the decade between 1995 and 2005, when GDP growth per capita averaged 1.8%, before declining thereafter.

Gordon's projections draw on the fact that the effects of ICT on TFP seem to have already peaked and no other major breakthrough is in sight. In particular, he claims that the research efforts are currently focused on the development of consumption devices (mostly in the areas of entertainment and communication), rather than on labor-saving innovations. Other findings corroborate this analysis. For example, the decline in the price index for ICT equipment, which was extremely steep in the mid-1990s, at annual rates in a range between -10% and -15%, attenuated thereafter and, in 2012, ICT prices barely fell at all (fig. 4). This result is presumably due to a sharp slowdown in TFP growth. Using sectoral data, Byrne et al. (2013) confirm that in the period 2004-2012 TFP slowed down in the ICT sector with respect to the previous decade and that the overall ICT contribution to labor productivity growth in the non-farm business sector diminished (this contribution being the sum of TFP growth in the ICT sector and capital deepening due to ICT equipment). In the period 2004-2012, both TFP growth in the ICT sector and the overall ICT contribution to labor productivity growth returned to the levels observed between the mid-1970s and 1994.

Based on these findings, Gordon (2014) projects that future TFP growth will fluctuate around the same average rate it has recorded since 1972, which is 0.6 percentage points lower with respect to the annual growth rate observed in the entire post-World War II period. This view is apparently shared by many others (see, inter

[12] According to other studies, economic stagnation dates back at least to the end of the Roman empire, as shown by the fact that the standard of living in ancient Rome was similar to that of Europe in the XVIII century (Temin, 2006).

Figure 4: Price deflator for all ICT equipment (1)



(1) Annual growth rate; percentages, quarterly data. Source: Gordon (2014) and Bureau of Economic Analysis.

alia, Cowen, 2011, and Vijg, 2011), including international organizations such as the OECD. In projecting long-run economic growth, the OECD (2014a) predicts, in fact, that TFP growth will be temporarily equal to 1.7% in the period 2012-2030 and that it will then decline to 1.1% in the subsequent 30 years.

3.2 Human capital

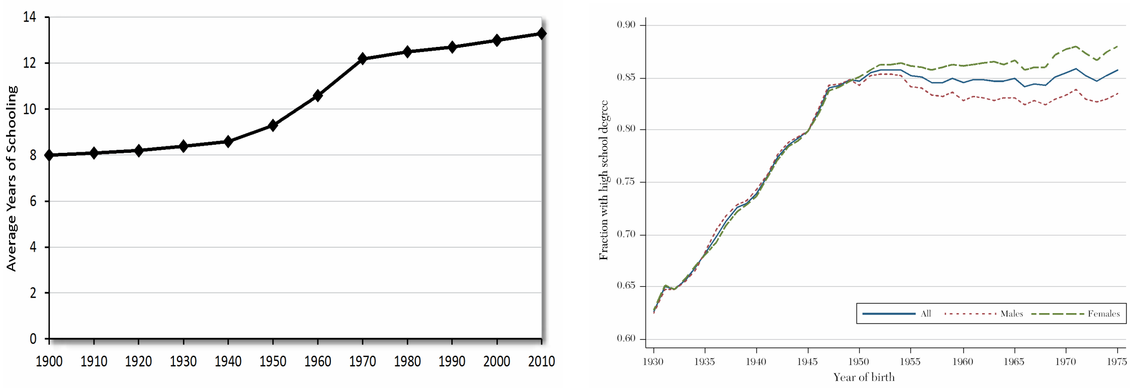
Human capital accumulation has been a significant contributor to U.S. economic growth. The main factor behind its increase is the exceptional rise in the years spent in school by U.S. residents. Overall, the average number of years of schooling completed by Americans aged at least 25 years old rose by about two-thirds between 1900 and 2010, from 8 to almost 14 years (fig. 5, panel *a*).

Educational attainments, however, seem to be close to a plateau. Consider, for example, the ratio of high-school graduates to 18-year-olds. This ratio, which was only 6% in 1900, had climbed to about 80% by 1970;[13] very recent estimates, however, find that the share of 18-year-olds with high-school diplomas flattened in the subsequent 30

[13] Goldin and Katz (2008) report a U.S. high school graduation rate equal to 77% in 1970, while Heckman and LaFontaine (2010) find a rate of 81%. As noted by Murnane (2013), estimates of graduation rates are sensitive to the choice of the data source and to the treatment of recent immigrants and of General Educational Development (GED) certificates. The GED program, in particular, is a test designed to certify the possession of high-school-level education. It was started as a small-scale program for military veterans and has now become a substitute for high school graduation, especially among minorities, as it is generally accepted for college admissions.

Figure 5: Average years of schooling and high school completion rates

(*a*) (*b*)



(*a*) Average years of schooling of Americans aged 25 and older. (*b*) High school completion rates by birth cohort: 1930-1975. Sources: Lindsey (2013) and Acemoglu and Autor (2012), based on U.S. census data.

years (Murnane, 2013). U.S. census cohort data confirm that the share of high-school graduates does not show visible signs of improvement since the class of people born in the early 1950s (fig. 5, panel *b*). The picture is similar for college attainment rates. The ratio of college graduates to 23-year-olds, which was only 2% in 1900, had risen to 24% by 1980; by 2010, it had risen to 30%, but only thanks to the strong increase in women's attainment rates, while for men it remained at roughly the same level as in 1980.

Many authors believe that the contribution of human capital accumulation to U.S. economic growth will slow sharply in the next few decades. One obvious reason for this is the fact that graduation rates cannot grow above 100%, so their sharp rise observed since the start of the XX century, which continued after World War II, cannot go on forever. In addition, education cannot last for people's entire life: at one point, students must leave school and start working to pay back schooling costs and take advantage of their education. From this perspective, the current maximum years of schooling (those achieved by doctoral and post-doctoral students) appear to be close to a reasonable peak and, as a consequence, average years of schooling may have limited margins for increasing further in the U.S.. This is also because some graduation rates, such as those regarding high school, seem to be already very close to a physiological maximum, despite being still below 100%. For example, Murnane (2013) finds that high-school graduation reached almost 85% in 2010 and, as also pointed out by Heckman and LaFontaine (2010), a significant portion of the remaining 15% share is explained by the higher dropout rates among the military, minorities (blacks and

Hispanics) as well as by young people sent to prison.[14]

Another reason for the possible slowdown of human capital accumulation is that, since the early 1970s, the cost of university education has more than tripled with respect to the overall rate of inflation, making enrollment inaccessible for many young people. Increasing difficulties in finding college-level jobs after graduation are also making college tuition and fees less affordable. Gordon (2014) suggests that, although a college degree still pays off in terms of higher income and lower risk of unemployment, about one-fourth of college graduates does not obtain a college-level job in the first few years after graduation.

According to Jorgenson et al. (2005), the annual growth rate of human capital due to both increased schooling and the rising level of worker experience will decline to about 0.1% in 2010-2020 (from 0.4% per year in 1950-2007) — almost a complete halt.[15] Similarly, the OECD (2014a) projects that human capital will increase at an annual rate of just 0.1% in 2012-2030 and by 0.2% in the following 30 years.

3.3 Employment ratio

The rise in the ratio of the total number of hours worked to the total population accounts for 6% of U.S. post-war economic growth. This is, however, the result of very different dynamics.

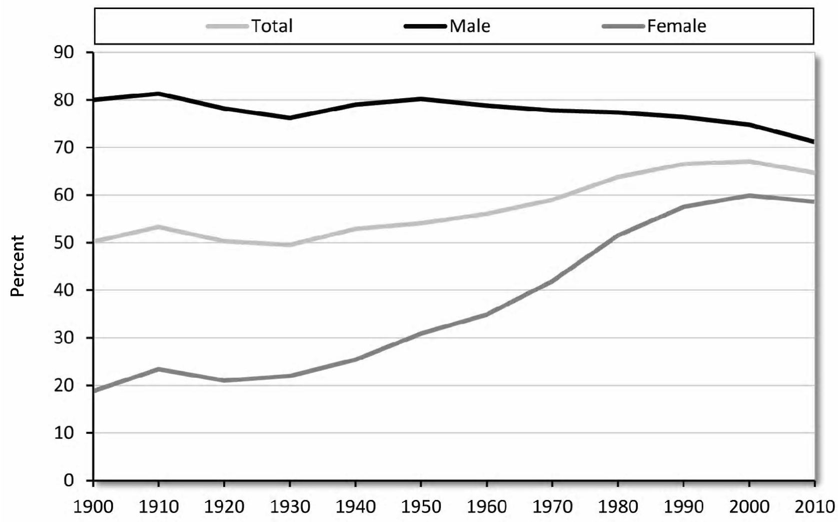
The first and most important factor supporting the employment ratio has been the movement of women into the labor force, which occurred mostly between 1950 and the early 2000s (fig. 6).[16] The female participation rate rose from less than 20% to 60% during the XX century, before declining somewhat in the last 10 years. The baby boom, which started in 1946 and lasted almost 20 years, was the second factor supporting the growth of the labor force, especially between the 1970s and the early 2000s, when baby boomers were in their prime working years (aged 25-54), when the participation rate is highest.

[14] A significant portion is also explained by the gender gap, which reflects the higher graduation rates of females common to most OECD countries.

[15] The projections on human capital accumulation, based on the methodology of Jorgenson et al. (2005), were updated by Dale Jorgenson in 2012 and reported in Byrne et al. (2013) and Gordon (2014).

[16] As argued by Gordon (2012), innovations such as running water and indoor plumbing were key determinants of this phenomenon. Before their diffusion, in fact, water for laundry, cooking and indoor chamber pots was hauled by housewives. For example, Strasser (1982) reports that, in 1885, the average North Carolina housewife walked 148 miles per year carrying 35 tons of water. Running water and indoor plumbing spread into all American houses between 1890 and 1930. A deeper theory, however, should explain why these inventions, which were already present in Mesopotamia and Egypt over 2,500 years BC and were extensively used in the Roman Empire, did not spread to North America until at the beginning of the early XX century.

Figure 6: Labor force participation rate by gender



Sources: Lindsey (2013), based on *Historical statistics of the United States*.

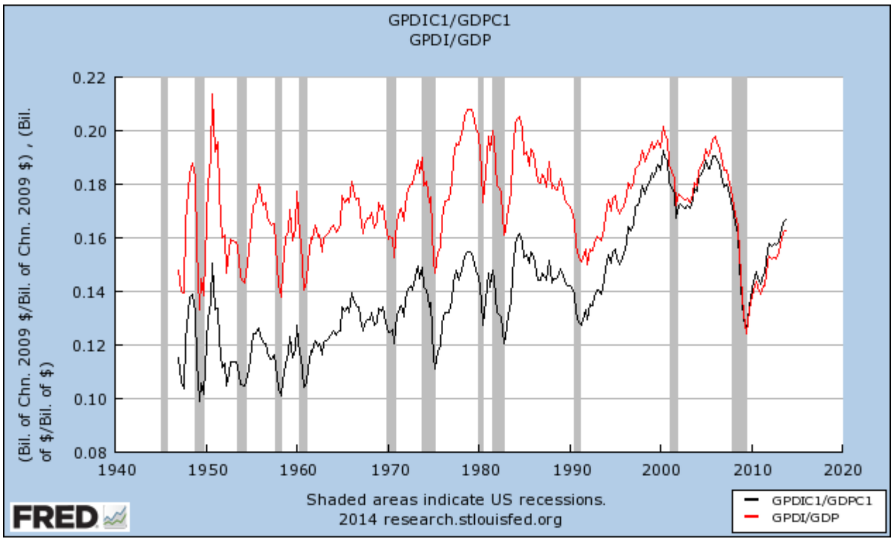
On the other hand, the growth of the employment ratio was dampened by a reduction in the participation rate of men, which started as early as in 1950, and, most importantly, by the decrease in the number of hours worked. The average number of weekly hours worked, equal to about 60 in 1890, had fallen to 37 in 1950, ending up at less than 33 in 2012.[17]

Thus, as for human capital, which was sustained by the rapid spread of education to all American workers, the employment ratio was sustained by a big "one-time event", namely the participation of women in the labor force. On a balanced-growth path the contribution of this variable should be nil, but, since 2008, baby boomers have started to retire and this demographic trend is expected to continue to negatively affect the employment ratio over the next two decades. As a consequence, even if participation rates were to stabilize for any age class and gender, the retirement of baby boomers would make the size of the labor force decrease relative to the total population, resulting in a negative trend of the employment ratio over the next two decades.

According to the OECD (2014a), the employment ratio, which had already started to diminish before the Great Recession (at an annual rate of -0.2% in 2000-2007), will decline further in 2012-2030, at a rate of -0.3% per year. In particular, the participation rate of people aged 15 and older, is forecast to decline by almost 4 percentage points, to 58.5%. The employment ratio is projected to recover somewhat in 2030-2060, when it will grow at 0.1% per year.

[17] The estimate for the number of hours worked in 1890 is referred to the manufacturing sector; this is a slightly higher figure than in other sectors, such as construction and railroads (*www.eh.net*).

Figure 7: U.S. investment shares (1)



(1) Real investment ($GPDIC1$) as a share of real GDP ($GDPC1$) and nominal investment ($GPDI$) as a share of nominal GDP (GDP). Quarterly data, seasonally adjusted annual rate. Source: Federal Reserve.

3.4 Capital-output ratio

The contribution of the capital-output ratio to U.S. economic growth has been nil over the post-World War II period. Many economists, however, have recently started to fear that this contribution could become negative, given that investment rates have declined substantially following the Great Recession (see, for example, Lindsey, 2013, and BIS, 2014, OECD, 2014b). Low investment is considered worrisome also because less physical capital could imply a limited diffusion of new technologies among firms, with a negative effect on both labor productivity and TFP growth.

After collapsing in 2008-2009 to the lowest values since World War II, the share of *nominal* investment over *nominal* GDP, the indicator that is most often used for cross-country comparisons, stood at 16.3% in the fourth quarter of 2013 (fig. 7). This level is among the lowest on record during expansionary phases of the business cycle.

This indicator, however, is biased, due to the well-known declining trend of capital good prices relative to overall prices (Gordon, 1990). The share of *real* investment in *real* GDP — which is not affected by relative prices — was equal to 16.7% in the fourth quarter of 2013 (fig. 7). More than four years after the end of the recession, this value is still lower than its steady state level, which is estimated at 17.2% by the OECD (2014b). The delayed recovery of the investment share, however, seems to be entirely ascribable to the severity of the last recession. In fact, the drop in this investment share during the Great Recession was much larger than for all the previous contractions, equal to almost 7 percentage points, against an average drop of less than

3 percentage points in the previous ten recessions. Even without resorting to precise statistical analysis, the current rise in the investment share does not appear to be less steep than in the past expansionary phases of the business cycle. Thus, the gradual return of the investment share toward its steady state suggests that the capital-output ratio should not pose an obstacle to long-run labor productivity growth.

The OECD (2014a), in fact, projects that the growth of the capital-output ratio will continue to be approximately nil over the next 50 years. The contribution to U.S. economic growth will be marginally positive in 2012-2030 (when it will increase at an annual rate of 0.1%), as physical capital will be rebuilt after the Great Recession, and marginally negative thereafter (−0.1%).

3.5 Summing up

The rise in the employment ratio, human capital accumulation and the stability of the capital-output ratio contributed 0.5 percentage points to the growth of GDP per capita in the post-war period. According to the OECD (2014a), this contribution could turn negative, at −0.1 percentage points, over the next two decades and then return positive, at 0.2 percentage points, in 2030-2060. This is in line with Gordon's projection that the contribution of these factors would be nil in the next 20 to 50 years. Therefore, because of these factors, the growth rate of GDP per capita could be lower by about 0.5 percentage points until 2060.

If the acceleration of technology improvements forecasted by the OECD for the period 2012-2030 does not materialize and TFP growth remains equal to the rates observed since 1972 (1.0%, as against 1.6% in 1950-2007), as Gordon predicts, then the growth rate of GDP per capita will be lower by a further 0.6 percentage points — a forecast that is substantially shared, for the period 2030-2060, by the OECD.

Overall, then, GDP per capita could increase at a rate of only 1.1% until 2060, against a rate of 2.2% recorded in 1950-2007.

4 Growth, research intensity and size effect

The results of the previous section have shown that the most important source of economic growth (in the U.S., but also in most other advanced and developing countries) is TFP, a variable whose dynamic is assumed to be exogenous, estimated as a residual, and whose ultimate determinants have not been spelled out. This is clearly not satisfactory.[18]

[18] Results from endogenous growth models, which explore the factors that can potentially explain long-run economic growth, are similarly unsatisfactory. These models identify several possible determinants of productivity growth, such as trade openness, government policies, the strength of property

Another challenge to growth models is the finding that the search for innovation — as measured by the number of scientists and engineers engaged in research and development (R&D) or by expenditure on R&D — has grown very sharply. For example, the share of U.S. workers employed in R&D, which was 0.25% in 1950, by the mid-2000s had risen fourfold, to 1%.[19] To come to grips with this phenomenon, Jones (2002) assumes that TFP growth has the following functional form:

$$\frac{\dot{A}_t}{A_t} = \beta \cdot \bar{R}_t \cdot A_t^{\phi-1} \tag{7}$$

where $\beta > 0$ is a constant, ϕ a parameter that specifies the returns (decreasing, constant or increasing) on research activity, and $\bar{R}_t$ the number of researchers (where we put a bar to mean that, as we explain below, the relevant number of researchers may include foreign researchers). The rationale of equation (7) is the following. First, TFP increases because workers employed in R&D develop non-rival ideas on how to organize inputs to produce more output. Because of non-rivalry, income per capita depends on the total number of ideas in the economy and not on the number of ideas per person. On a balanced-growth path, the number of researchers is a constant share of the labor force; the latter, in turn, is a constant share of the total population and, therefore, *the level of TFP depends on the size of the population.* In other words, more population means more potential inventors so that, in the long run, the growth of income per capita is driven uniquely by population growth. Second, the growth rate of TFP also depends on the level of TFP, in order to account for potentially non-constant returns to scale in the search for ideas. In particular, $\phi < 1$ ($\phi > 1$) implies diminishing (increasing) returns to the research activity, while $\phi = 1$ implies constant returns.

Simple algebra shows that, if TFP evolves according to equation (7), on a constant-growth path the decomposition (5) transforms into:

$$\frac{Y_t}{P_t} = \frac{L_t}{P_t} \cdot \left(\frac{\bar{R}_t}{\bar{L}_t}\right)^{\gamma} \cdot \bar{L}_t^{\gamma} \cdot \left(\frac{K_t}{Y_t}\right)^{\alpha/(1-\alpha)} \cdot h_t \ , \tag{8}$$

where $\gamma = \sigma\left[(1-\phi)(1-\alpha)\right]^{-1}$. This is the same decomposition as in equation (5), except that now, due to (7), the exogenous growth of TFP is split into two terms that, together, correspond to the stock of ideas. The former is $\bar{R}_t/\bar{L}_t$, which represents *research intensity*, i.e. the strength of the hunt for new ideas. The latter is a *size effect*, measured by the total number of workers in the economy $\bar{L}_t$, which is the

rights, competition and regulatory pressures. Permanent changes in these variables, which have frequently occurred throughout U.S. history, should lead to permanent changes in economic growth rates. The theoretical relevance of these changes, however, contrasts with the aforementioned empirical stability of long-run growth.

[19] The increase in the share of researches for the average of the five largest OECD economies (France, Germany, Japan, U.K. and U.S.) is equally striking: such share rose from 0.16% in 1950 to 0.95% in 2007.

denominator of research intensity.[20] The relevant researchers, those who can help push the technology frontier outward, do not necessarily live in the U.S.. Therefore, $\bar{R}_t$ and $\bar{L}_t$ may refer to researchers and workers who are also in other countries. For example, Jones (2002) assumes that the researchers able to extend the frontiers of knowledge are residents of the five largest OECD countries (France, Germany, Japan, the U.K., and the U.S.).

The growth rate of TFP between 1950 and 2007, equal to 1.6% (equation (6)), can thus be decomposed into the growth rate of *research intensity* and the *size effect*. In the following quantification, in which we use data from Fernald and Jones (2014), we retain the same notation as equation (6) and we also denote with $\dot{r}$ and $\dot{l}$ the growth rates of, respectively, the share of researchers ($r_t = \bar{R}_t/\bar{L}_t$) and the labor force of the countries where researches live ($\bar{L}_t$):

$$\underset{\substack{1.6\% \\ (74\%)}}{\frac{\sigma}{1-\alpha}\dot{a}} = \underset{\substack{1.2 \\ (54\%)}}{\gamma\dot{r}} + \underset{\substack{0.4 \\ (20\%)}}{\gamma\dot{l}} \quad . \tag{9}$$

Equation (9) shows that the exogenous growth rate of TFP, which was equal to 1.6% per year during the period 1950-2007, can be decomposed into a rate of 1.2% due to *research intensity* and 0.4% due to the *size effect*.[21] The value of γ resulting from the decomposition implies that ϕ is smaller than 1 and, therefore, that there are diminishing returns to scale on research.[22]

The results reported in equations (6) and (9) highlight that, between 1950 and 2007, 80% of U.S. economic growth reflected transitory factors. As mentioned above, in fact, in these models the rise of the population is the key determinant of long-run economic growth; therefore, only the size effect can generate sustainable growth. The employment ratio and research intensity are shares and, as such, cannot grow forever. Moreover, as discussed in the previous section, many authors believe that also human capital cannot increase indefinitely either. Some of these factors, especially the share of researchers and human capital, may still have margins to increase for some time but, in the very long run, this theory implies that economic growth should revert to the growth rate of the population.

Gordon's projection of an increase of TFP at an annual rate of 1.0% for the next few decades appears consistent with the outlook for research intensity and the size effect. Let us assume that research intensity continues to grow until 2030 at the same

[20] In equation (7), ideas arrive in a deterministic fashion. Kortum (1997) builds a general equilibrium model in which the flow of ideas is stochastic, which yields the same implication that a growing number of researchers generates a constant productivity growth.

[21] We recall that 74% is the share of the contribution of TFP to the overall annual growth of GDP per capita (see equation (6)).

[22] Since the parameter σ can be normalized to 1 and given that $\dot{r}$ and $\dot{l}$ are equal to, respectively, 3.1% and 1.1%, it follows that γ is equal to 0.38.

rate of 1.8% as the one observed since 1972 (the time period that Gordon labelled the "Third Industrial Revolution");[23] moreover, U.S. census forecast data indicate annual growth of 0.8% of the U.S. labor force until 2030, which is consistent with the projections of the OECD (2014a). By applying the value of γ derived above, we obtain a prediction for the sum of $\gamma\dot{r}$ and $\gamma\dot{l}$ of 1.0%, which confirms Gordon's projection.

5 Unequal growth

In the previous sections, we focused on GDP per capita, deriving the sources of its past growth as well as its future prospects from a model with a representative consumer. This analysis, however, neglects an important phenomenon that has occurred during the last three decades and that we discuss in this section, that is the *rise of income inequality.*

To understand why this phenomenon matters for our analysis, take, for example, the related and well-documented increase in the share of total income received by the households in the top 1% of the income distribution. If we refer economic development and welfare to 99% of the households and, in particular, to the households in the bottom 99% of the income distribution, rather than to the mean household as we have implicitly done in the previous sections, then growth has already been stagnating for more than 30 years.[24]

But income inequality is also important for assessing the equilibrium interest rate. Households in upper percentiles of the income distribution have higher propensities to save. It follows that, for a given average income, a more unequal income distribution implies higher savings that, in order to be matched with higher investments, require a lower interest rate.[25] As we know from Section 2, a lower growth rate of GDP per capita implies that the equilibrium interest rate declines and this decline is stronger if lower economic growth is accompanied by higher income inequality.[26]

[23] This would bring the share of researchers to 1.4% in 2030, which seems a reasonable figure.

[24] Between 1973 and 2012, real income for the households in the bottom 99% has grown, on average, at mere 0.1% per year (Alvaredo, Atkinson, Piketty, Saez, 2013). During the same period and perhaps more surprisingly, real hourly wages of men have *declined* for the workers in the bottom 60% of the wage distribution.

[25] In an overlapping generations model, Eggertsson and Mehrotra (2014) show examples in which, under plausible conditions, a more unequal income distribution (either across generations or within the same cohort) raises savings and reduces the real interest rate. In general, however, the larger share of low income borrowers induced by a higher income inequality boosts the demand for loans, with potential offsetting effects on the real interest rate. Whether inequality raises or lowers interest rates, then, depends on the details of the distribution of income across and within generations as well as on the type of credit constraints.

[26] In this paper we neglect the heated debate of whether rising inequality undermines economic growth (see, for example, the recent work by Ostry, Berg and Tsangarides, 2014, and the references

The rise of income inequality is the result of two main phenomena: the *decline of the labor share of income* and the *increase of wage inequality.* Their role in determining income inequality is clear. A decline in the labor share, in fact, corresponds to an increase in the share of profits. Because profits typically go, as distributed dividends, to the households in the top percentiles of the income distribution, this phenomenon adds to the effects of rising wage inequality, thereby further increasing income inequality.[27] In the following section we analyze the evolution of the labor share and of wage inequality separately, starting with the first phenomenon. We then review the possible implications for the incomes of the households in the bottom 99% of the income distribution.

5.1 Labor share of income

The stability of the labor share has been a fundamental feature of macroeconomic models since Kaldor (1957). In a recent work, however, Karabarbounis and Neiman (2014) document that the labor share has decreased significantly in the great majority of countries and industries since the early 1980s, with a decline in the order of 5 percentage points for the cross-country average (the labor share of the four largest countries is reported in fig. 8; more details for the U.S. are in Elsby et al., 2013). In particular, of the 59 countries with at least 15 years of data between 1975 and 2012, 42 exhibited downward trends in their labor shares and, of these, 39 have trend estimates that are statistically significant. In addition, sectoral data show that most of the global decline in the labor share is attributable to within-industry changes and not to changes in the industrial composition of production.

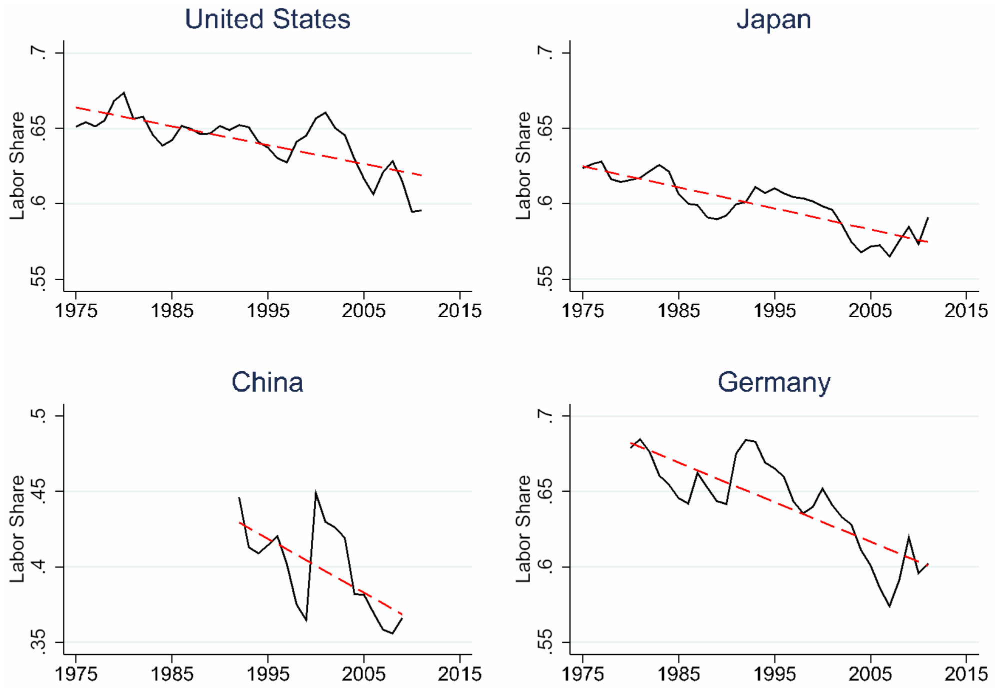
The widespread nature of this decline, which involves not only capital-abundant advanced countries but also labor-abundant economies such as China, India and Mexico, calls for explanations that are common across countries. At the same time, global factors with effects that are differentiated across countries (such as increased trade openness and outsourcing) or country-specific shocks (such as changes in domestic institutions) should be less important.

A natural candidate explanation for the behavior of the labor share is the sharp decline in the price of capital goods relative to consumption goods that has occurred since the 1970s (Gordon, 1990), which, in turn, is associated with the rapid diffusion of ICT in the workplace. This phenomenon, in fact, was widespread across many countries and took place at broadly the same time as the decline of the labor share.

therein).

[27]Note that in the model with a representative consumer, an increase in the capital share raises the equilibrium interest rate: because more physical capital is needed for production, then more investment is required to generate that physical capital. The outcome would be different, instead, with heterogeneous consumers and different propensities to save.

Figure 8: Labor Share for the Largest Countries



Source: Karabarbounis and Neiman (2014).

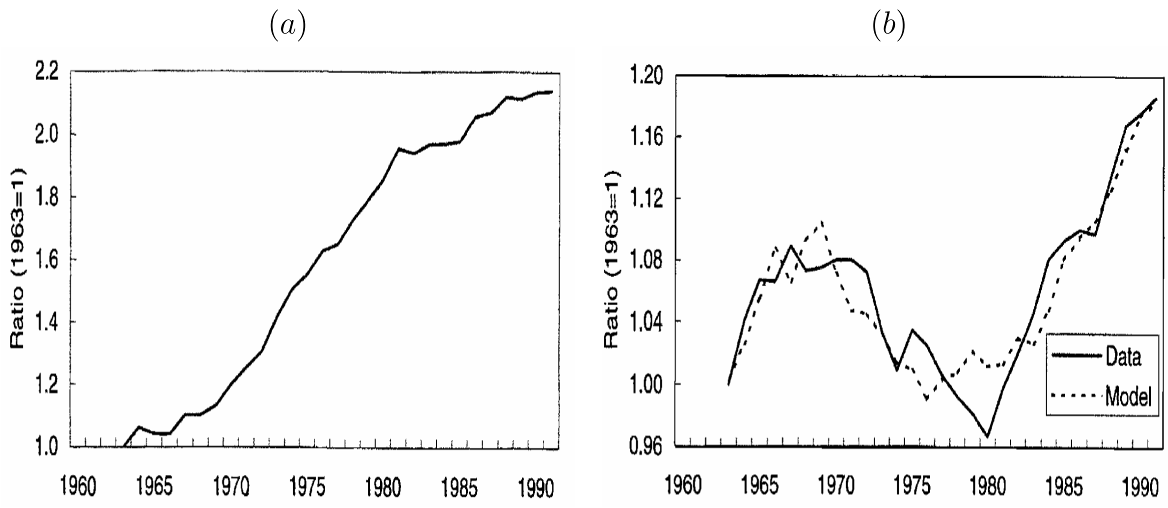
Karabarbounis and Neiman (2014) build a growth model with a CES production function in which, unlike the Cobb-Douglas function used in equation (3), the elasticity of substitution between labor and physical capital can be potentially different from 1. Their estimates show that such elasticity is indeed larger than 1, equal to 1.25. Using this estimate, they show that the decline in the relative price of capital goods (equal to 25% between 1975 and 2012) explains about half of the reduction of the labor share — a result that turns out to be robust to several modifications of their benchmark model.

5.2 Wage inequality

The increasing availability of large-scale micro data in recent years has favored an explosion of studies on the distribution of wages across workers. These studies show that in many OECD countries the wage structure has changed considerably over the last decades.

In general, wage differentials across workers have several dimensions: they depend on the level of education of workers, their gender, their experience, the type of job, and the industry and sector where they are employed. With the exception of the difference between genders, which has diminished since the mid-1970s, all the other wage differentials have tended to increase since at least the late 1970s, including the

Figure 9: Skilled and unskilled workers: relative size and relative wage (1)



(1) Annual data from 1963 to 1991; indices: 1963=100. (a) Hours worked of skilled workers (at least college degree) relative to unskilled workers. (b) Skill premium: wages per hour of skilled relative to unskilled workers (normalized: 1963=1). Source: Krusell et al. (2000).

residual, unexplained wage dispersion (Katz and Autor, 1999). In this section, we focus on the wage differential between "skilled" workers, identified as those with at least a college degree, and "unskilled" workers, those with lower educational attainments; this is the standard form of *skill premium*, which is closely related to technical change.

After narrowing substantially in all countries in the post-World War II period until the 1970s, the educational skill premium followed somewhat different patterns. In the U.S. and U.K., educational wage differentials have increased greatly since the late 1970s. In most other OECD countries, instead, increases have been more modest (see Katz and Autor, 1999, and, for the U.S., Heathcote et al., 2010).[28]

Explaining the rise in the skill premium over the last three decades is complicated by the fact that, as we have discussed in the previous sections, the supply of skilled labor has increased substantially since 1900 and this trend continued after the 1970s (for the U.S. see fig 9, panel a). Two main explanations have emerged in the literature: one focuses on changes in technology that raise the demand for skilled workers, the other on the role of international trade.

The former explanation was put forward, in particular, in a very influential paper by Krusell et al. (2000). These authors developed a model in which production

[28] It is worth noting that, despite lower gender gaps and the increased share of women in the workforce, wage dispersion between family heads has translated into greater income inequality, because the correlation in the earnings of husbands and wives has also risen (Katz and Autor, 1999).

occurs using capital equipment and two types of labor, skilled and unskilled.[29] In the model, they allow for different elasticities of substitution between unskilled labor and capital equipment (σ_{uk}) and between skilled labor and capital equipment (σ_{sk}). Their calibrations confirm the pioneering finding of Griliches (1969) about the existence of a *capital-skill complementarity*: the elasticity of substitution between skilled labor and capital equipment turns out to be smaller than 1, while the elasticity of substitution between unskilled labor and capital equipment is found to be larger than 1 (i.e.: $\sigma_{sk} < 1 < \sigma_{uk}$).[30] In this context, the decline in the relative price of capital goods becomes a form of *skill-biased technological progress*: it favors the substitution of unskilled labor with capital and, at the same time, it requires more skilled workers to complement the rise in the capital stock. Krusell et al. (2000) show that *the capital-skill complementarity, coupled with the decline in the relative price of capital goods, is able to explain almost the entire dynamic of the skill premium observed in the U.S. between 1963 and 1991* (see fig. 9, panel *b*). In a counterfactual simulation, these authors also assume $\sigma_{sk} = \sigma_{uk} > 1$, shutting off the capital skill complementarity, to show that, due to the large increase in the relative size of skilled labor over the sample period, without the capital-skill complementarity the skill premium would have declined by 40% instead of rising by 20%.[31]

The different dynamics of the skill premium across different countries, however, open the way to other complementary explanations. Burstein and Vogel (2012) focus on the effects of international trade. They consider a standard Heckscher-Ohlin model, in which countries differ in the endowment of skilled and unskilled labor and sectoral production differs by the intensity of the use of the two factors, and modify two main aspects of it. First, they consider firms that, in each sector, have heterogeneous productivity, to account for the fact that trade is mostly within sectors and that exporting firms are generally larger and more productive. Second, within each sector, firms differ not only in productivity but also in the intensity of the use of skilled workers, to account for the fact that, within each sector, exporters tend to be more skill intensive than non-exporters. In this setting, reductions in trade costs have two main effects. On the one hand, the reallocation of demand across sectors follows the law of comparative advantage; then, lower trade costs increase the skill premium in skill-abundant countries and decrease it in skill-scarce countries. On the other hand, enhanced competition from foreign countries tends to raise demand for more productive exporters

[29]In the model, they also consider a second type of physical capital, *capital structure*, that is similar to general-purpose technology.

[30]In the model, they only assume that $\sigma_{sk} < \sigma_{uk}$. The calibration returns $\sigma_{sk} = 0.67$ and $\sigma_{uk} = 1.67$, which are in line with many other available estimates.

[31]Krusell et al. (2000) also consider an explanation based on increased productivity of workers with a college degree with respect to those without. To be consistent with the data, this explanation would require that the productivity of the former should have increased 30 times more than the productivity of the latter. No other data, however, is consistent with this large difference.

within each sector: because all these firms have skill-intensive production, the skill premium tends to increase in all countries. By quantifying the model for a sample of 64 advanced and developing countries, Burstein and Vogel (2012) show that lowering trade costs from autarky to those observed in 2005-2007 has the following effects: (*i*) real wages for both skilled and unskilled workers increase in all countries; (*ii*) the rise in real wages for skilled workers, however, is more than twice as large as that for unskilled workers (in the median country); (*iii*) the skill premium rises everywhere, but varies widely across countries. In particular, *for small open economies like Costa Rica and Malaysia the skill premium increases by as much as* 20%*, but for large and relatively closed countries like the U.S. and Brazil, it increases by just* 2%.

5.3 Outlook

Predicting the evolution of income inequality requires not only a forecast about TFP growth but also, as discussed above, a forecast about whether TFP gains are concentrated on capital goods, rather than consumption goods. By contrast, given that the U.S. is almost a closed economy (because trade occurs mostly within the country, despite very low tariff and non-tariff barriers), the evolution of globalization is much less important.

As explained in Section 3, Gordon (2012 and 2014) makes his main prediction about TFP growth simply by projecting into the future the rise in TFP observed since 1972. By the same token, he projects that inequality will evolve in the same way as it has done since the early 1970s. In particular, GDP per tax-unit for the households in the bottom 99% of the income distribution has grown at an annual rate that is 0.5 percentage points lower than the rate recorded for the entire U.S. population.

In light of the results discussed above, this assessment appears to be a compromise between two opposite tendencies. On the one hand, to the extent that current research is focused mainly on the development of consumption devices, as Gordon asserts, this prediction might be pessimistic: productivity growth in the consumption-goods sector should attenuate both the decline in the labor share and the skill premium, reducing inequality growth. On the other hand, lower human capital accumulation, i.e. lower growth in the number of college-graduate workers, should push up their wages, amplifying the skill premium and income inequality.

6 Insights from economic history

The analysis developed in the previous sections has shown that the most important factors that one should consider in order to predict long-term economic growth are *TFP*, *population* (which, in turn, contributes to TFP), *human capital* and, to the extent that the policy-maker is interested in more than mere GDP growth for the average individual, *income inequality.* In this section, we examine these factors from a broader historical perspective.

The debate on secular stagnation is, in fact, a *cyclical question*: it has been raised following almost any deep and prolonged recession. It may be useful, then, to briefly review the data and arguments that were analyzed in the past, in order to understand, with the benefit of hindsight, the reasons why pessimistic predictions turned out to be wrong. As exemplified by the work of Alvin Hansen during the 1930s,[32] the debate has often revolved around the issues of technical change and population growth.[33] Therefore, after revisiting these "older concerns", we turn to the two features that have been incorporated in neoclassical models of economic growth only more recently, human capital and income inequality, and examine them through the lenses of a longer-run perspective.

6.1 Older concerns: TFP and population

Economic historians remind us that the question of secular stagnation has been raised several times over the last century, and especially after strong recessions, such as in the aftermath of the Long Depression of 1873-1879 and the Great Depression of 1929-1933, towards the end of World War II, during the stagnation of the 1970s, and again in the late 1980s.[34]

Interestingly, many alarming signs identified today are quite similar to those considered by Alvin Hansen in 1938, during the recovery that followed the Great Depression. As in much of the earlier and subsequent literature, Hansen was especially worried about the development of two key factors: technical change and population.

As regards technical change, Hansen acknowledged that *inventions* were the main determinants of economic growth and related their development to capital deepening.[35] His worries stemmed from the fact that, in his view, the period 1934-1937 had been a "consumption recovery", with insufficient investment. His analysis was also grounded

[32] Alvin Hansen (1887-1975), often referred to as "the American Keynes" (Nasar, 2012), was a professor of economics at Harvard and an influential advisor to the government, who helped create the Council of Economic Advisors and the Social Security System. He introduced Keynesian economics in the United States, clarifying its implications (Hansen, 1936). He was the mentor of Paul Samuelson, who credited him for inspiring the formalization of the multiplier-accelerator model (Samuelson, 1939).

[33] Other factors that have often been identified as posing significant threats to economic growth are a possible depletion of natural resources and pollution (see, for example, the famous study by Meadows et al., 1972).

[34] For a sample of the arguments raised in the historical periods mentioned above, see, in particular, Wells (1891), Hansen (1938 and 1939), Harris (1943), Nordhaus (1972), Baily and Gordon (1988), and Krugman (1990).

[35] Hansen distinguished between *capital deepening* and *capital widening*, depending on whether physical capital grew at a rate, respectively, higher or equal to that of output.

in the apparent prospects of U.S. industries. In particular, he claimed that the main engines that fuelled growth in the XIX century — steel, textiles and railroads — had been exhausted; on the other hand, the newest drivers of innovation — automobiles and the radio — had already become mature.[36]

Population was considered as a key determinant of inventions, not only indirectly, because it stimulated capital deepening, but also directly, because it "facilitated mass production methods and accelerated the progress of technique". This view, in the tradition of Adam Smith, is very similar to the modern view of Kremer (1993) and Jones (2002), and contrary to the Malthusian theory. Hansen (1939) observed that the population growth rate had halved and estimated that, in the second half of the XIX century, population growth had contributed to about 60% of the increase in the capital stock.[37] Therefore, he deemed that "a rapid cessation of population growth" could have a strong negative impact on capital formation and TFP. Moreover, in the tradition of the emerging Keynesian economics, Hansen was convinced that the combined effect of the decline in population growth and the lack of innovations of significant magnitude were the premises not only of a prolonged stagnation, but also explained the failure of the recovery to reach full employment.[38]

The stagnation, as we know, did not materialize. It may prove useful, then, to review the reasons why Hansen's predictions failed, in spite of their reliance on sound evidence and arguments, as data did support the slowdown of TFP and population, while lower population growth had been correctly identified as a factor that could have weakened the incentives to innovate. First, concerning technology, *the contribution of electricity to TFP had been surprisingly neglected.* Yet, the "electrification of America" was one of the main developments of the early XX century (Nye, 1990). For example, in 1899 electric lighting was used in a mere 3% of all U.S. residences; in the following two decades, electrification had already reached 50% of all residences and establishments; after 1917, when its cost declined substantially, the diffusion of electricity rapidly became almost universal (David, 1990). With the wide coverage achieved by electricity, inventors turned to the development of consumer goods: by the 1930s, the commercialization of many home appliances had already started, although the boom did not occur after World War II. Second, *the assessment of the maturity of the automobile industry turned out to be incorrect.* The production of automobiles increased further after the 1930s and spread to other countries. This phenomenon continued to

[36]Merton (1935), for example, showed that the number of patents issued for inventions related to the automobile and the radio industry had started to decline in the early 1920s; in the aeroplane industry, the decline had started even earlier, in 1918.

[37]Following similar remarks by Keynes (1937), Hansen (1939) noted that U.S. residents had increased by 16 millions during the 1920s (17 millions according to the most recently revised data), while in the 1930s the rise was estimated to be in the order of 8 million (9 million using modern data).

[38]Fifty years later, Samuelson formalized this argument in the Keynes-Hansen-Samuelson multiplier-accelerator model of secular stagnation (Samuelson, 1988).

fuel the growth of inventions to our days: in 2012 the automobile industry was still the third highest-ranking industry for patent generation (preceded only by "telecommunications" and "computers and peripherals"). Third, it is also surprising that *the possibility that television would replace the radio was altogether ignored.* Although television was popularized only at the New York World Fair in 1939, in the late 1920s its commercialization had already begun (although in limited amounts); the ancestors of CBS and NBC (WRGB and W2XBS, respectively) started broadcasting in 1928; in 1932 Telefunken sold the first televisions with cathode-ray tubes in Germany, soon followed by other manufacturers in France and the U.K.; the BBC began broadcasting in 1936. Fourth, turning to population, *the annual rate of growth of U.S. residents turned out to be less predictable than what was previously thought*: after averaging only 0.6% during the entire recovery of 1934-1937, in 1941 it was already above 1.0% and then, in 1947, the baby boom started, lasting about 20 years, with growth rates of almost 2.0%.

In retrospect, this experience shows how easy it is to underestimate the potential of technologies *that already exist*, rather than the difficulty of predicting new technologies, and suggests that the pessimism about ICT may be unwarranted. *The spread of computers among U.S. households and businesses has matched that of electricity quite closely*: in less than four decades since the early 1970s, computers have entered almost all U.S. houses and workplaces, just like electricity did at the start of the XX century. Moreover, research in the ICT sector is currently turning to the development of consumption devices, resembling the shift towards home appliances that occurred in the 1920s and 1930s and that anticipated the economic boom observed after World War II.[39]

The skepticism about the contribution of ICT to TFP growth and its possible maturity also seems unjustified. As shown by Crafts (2002), the contribution of ICT to capital deepening and TFP growth in the U.S. in 1974-2000 was greater than the early contributions of the two other main general-purpose technologies developed during the Industrial Revolution, i.e. electricity (for the U.S. in 1899-1929) and steam (for the U.K. in 1780-1860).[40] Moreover, in the past, long periods of productivity slowdown occurred frequently during expansionary phases, such as in 1890-1913, after the Great Depression, and between the mid-1970s and mid-1990s. Following phases of lower growth, the U.S. economy has always entered periods of sharp upturn in productivity, leading to the long-run stability of GDP growth per capita. While one cannot take

[39] The commercialization of most home appliances — including refrigerators, washing machines, televisions, air conditioning, electric vacuum cleaners, electric toasters, etc. — started in the 1920s and 1930s (see Vijg, 2011, for a list of inventions).

[40] Crafts (2002) estimates that ICT has been responsible for 30% of the overall growth of GDP per capita in its first 15 years and 55% in the following 10 years. The contribution of electricity was broadly similar (28% in the first 30 years and 47% in the following 10 years), while that of steam was much smaller.

it for granted that such an acceleration will happen again, the current weakness of TFP growth is likely to be due to a process of resource reallocation across sectors induced by the Great Recession that is still incomplete and that may turn out to be only temporary. Finally, we should not forget that general-purpose technologies always took many decades to exert their full effects on the economy.[41] The technologies, tools and resources with the highest economic impact may have already been invented, but it may take time before they change our lives.[42]

More in general, *the key question concerning TFP is whether there are diminishing returns on research activity*; that is, whether making progress becomes increasingly difficult as technology advances. The fact that, historically, the number of patents granted could scarcely keep pace with the growth of population or with R&D expenditure has often been interpreted as evidence of diminishing returns (see, for example, Merton, 1935, or Griliches, 1990). This is, however, still a very open issue. *The stability of the growth rate of GDP per capita in the long run does not allow us to rule out that technological progress has instead a "fractal quality"*. In other words, it may well be that the probability that TFP increases does not depend on the level of TFP. Incidentally, it is worth noting that the Pareto distribution, which is often used to describe productivities in the cross-section of firms, has exactly this fractal property.[43] The alternative paths of TFP represented in Figure 10 seem to be all equally plausible, and more research is needed to explore the properties of both the evolution of aggregate TFP over time as well as those of TFP in the cross-section of individual firms.[44]

Regarding population, the experience of the XX century suggests that, in the medium-long term, its growth rates may fluctuate in a rather unpredictable way. More

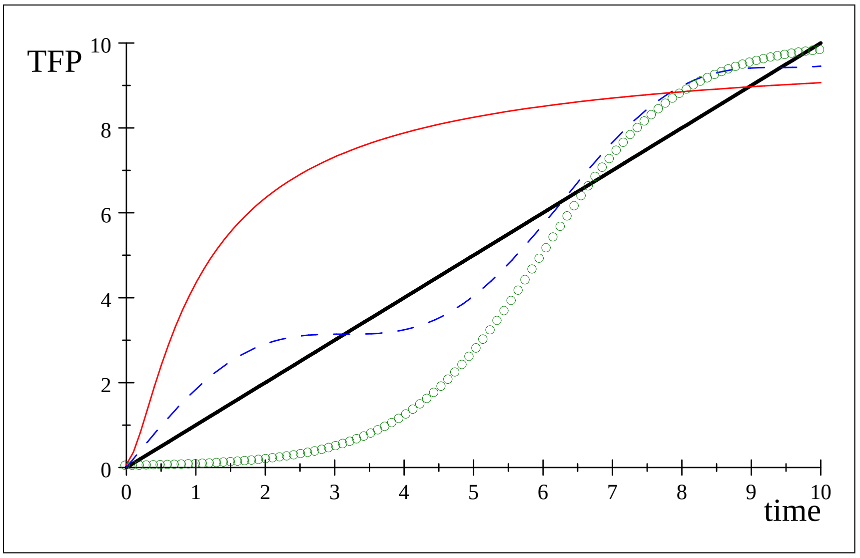
[41] As Joel Mokyr (2013) put it, 50 years after its invention, the steam engine was probably viewed has a machine that "made a lot of noise, emitted a lot of smoke and stench, and pumped some water out of few coal mines". Similarly, as remarked by Paul David in 1990 (rephrasing Robert Solow's famous quip), many observers living in 1900 might have asserted that electric dynamos were "everywhere but in the productivity statistics".

[42] Brynjolfsson and McAfee (2014) discuss several promising innovations, including recent developments in robotics, 3D-printers, self-driving cars, computer-aided diagnosis in medicine, possible offsprings from genome sequencing, etc.. Gordon (2014) and Vijg (2011) question the economic impact of most of them. Promising discoveries, however, seem to be made every day. Only recently a team of researchers claims to have, for the first time, extracted more energy from *controlled nuclear fusion* than was absorbed by the fuel to trigger it (Ball, 2014). If confirmed, this result would cross an important symbolic threshold on the path to exploiting this virtually unlimited source of energy.

[43] A truncated Pareto distribution, in fact, is still a Pareto distribution. To understand why this matters, assume, for example, that the TFP evolves stochastically, following a Pareto distribution; namely, $A_t \sim Pareto(1, \theta)$, where t is time (with A_t i.i.d.). Suppose, also, that technological progress is an increase in the level of TFP from a value of at least a' to a value of at least $a'' > a'$. Then, the probability that technological progress occurs is $\Pr\left(A_{t+1} > a'' | A_t > a'\right) = \left(a'/a''\right)^{\theta}$. As a consequence, raising a' and a'' proportionally does not change the probability that technological progress occurs.

[44] Finicelli et al. (2014) show, for both closed and open economies, that aggregate TFP is a specific moment (whose order depends on consumer preferences) of the distribution of TFP across firms.

Figure 10: Alternative paths of TFP growth (1)



(1) Thick solid line: constant returns to scale in the research activity; red solid line: decreasing returns to scale; green dotted line: first increasing and then decreasing returns to scale; blue dashed line: "variable" returns to scale.

importantly, the theory presented in Section 4 implies that *the relevant population for TFP growth is given by the people that can actually help push the technology frontier outward*. Many indicators, such as the increase in the share of U.S. patents granted to foreign residents, signal that this population no longer coincides with the U.S. labor force. The magnitude of the size effect for future TFP growth, then, is likely to benefit greatly from *the integration of emerging countries into the global economy and their future contributions to the technology frontier*.

6.2 Newer concerns:

6.2.1 human capital ...

Although the improvement of workers' skills as a source of economic progress goes back at least to Adam Smith, it was not until after World War II that human capital has been incorporated in neoclassical models of growth. From this perspective, the cornerstone in the quantification of human capital is the theoretical and empirical model of wages of Jacob Mincer (1958 and 1974). As a result of his work, human capital is still measured using data on schooling and workers' experience, as in equation (4).

To the extent that schooling and experience are the most relevant factors for workers' skills, however, two main problems emerge (see also Section 3). In the short run, the increasing relative costs of higher education are making it less affordable, thereby hampering human capital. In the longer run, human capital accumulation is bounded from above: work experience is limited by the retirement age, years of schooling by the fact that, well before the retirement age, students must exit school to repay education costs.

The problem of rising education costs could be effectively addressed by a varieties of policies and, then, projections for human capital growth could turn out to be pessimistic if they do not take this fact into account. For example, the *"higher education initiative"* of the U.S. government aims to keep costs down and make college education affordable.[45] But private initiatives are also helping to address the problem. One important phenomenon that is currently emerging is *the rapid proliferation of Internet-based educational resources*. In particular, lecture videos and other online teaching tools are making education almost "non-rivalrous". Acemoglu et al. (2014) have recently build a theoretical model to understand the possible consequences of this phenomenon. Their model predicts that, in the future, lectures could be provided by a handful of "superstar global teachers", while local teachers, freed from lecturing, would be allocated to other complementary activities. An important result of this model is a process of "democratization of education", in which high-quality educational resources will be more equally distributed.

Turning to the second problem, the main question that arises is whether measuring human capital by using the average number of years of schooling and work experience is still appropriate. One issue that also affects the measurement of physical capital concerns the quantification of the *quality of capital (i.e. its intensive margin)*. Attempts to exploit data on school resources and test scores as proxies for the quality of education in order to augment the quantity-based measure of human capital, however, lead to trivially small differences (for example, they are not helpful in explaining cross-country income differences; see Caselli, 2005).

An issue that has been neglected in the economic literature is the explosion of specializations in all fields of knowledge. A question that would be worth examining, then, is whether human capital can grow by extending *the varieties of knowledge (extensive margin)*, even if the average years of schooling remain constant. In fact, it is possible that the competencies of college graduates 60 years ago were more similar to each other than what they are today, given the much higher number of faculties, types of college degree and university courses that are currently offered. Thus, even though the average years of schooling for college graduates were the same as 60 years ago, the fact that, together, new college graduates embed a larger variety of competencies may provide an additional boost to economic growth. If this were true, human cap-

[45] The expiration of a part of the "Bush tax cuts" on higher incomes since January 1, 2013 is another measure that contributes to reduce after-tax income inequality. The current U.S. administration has also recently proposed to increase the minimum wage, a measure adopted in States like California and New York (while in other U.S. States minimum wages are increased annually based upon a cost of living formula).

ital could keep contributing to economic growth over and above the mere number of years of schooling. More in general, one could question the view that human capital is embodied only in each single individual and the related practice of measuring the aggregate stock of human capital simply as the sum of these individual stocks. Further research is needed to understand whether the aggregate stock of human capital is more than just the sum of the stocks of the single individuals and whether it also depends on the varieties of knowledge, the way individuals interact with each other, etc..[46]

6.2.2 ... and inequality

Even though income inequality has been one of the key issues since the very birth of classical political economy in the XVIII century, for a long time studies on the income distribution were based only on very few facts and were instead built on a wide variety of purely theoretical speculations (Piketty, 2014). For example, the theory put forth by Kuznets (1953 and 1955), who conjectured that income inequality increases in the early stages of economic development and then decreases after a certain average income is attained, was based on very precise data only for the period 1913-1948, in which inequality declined constantly, and scant evidence, at best, for the late XIX century.[47] This is because the main data source for studies on income inequality are tax records and, although taxes were systematically collected even in antiquity, the introduction of income taxes is been relatively recent. In the U.S., in particular, personal income tax was temporarily introduced, for the first time, during the Civil War (in 1861, only to be repealed the following year) and did not became a permanent component of the U.S. tax system until 1913.

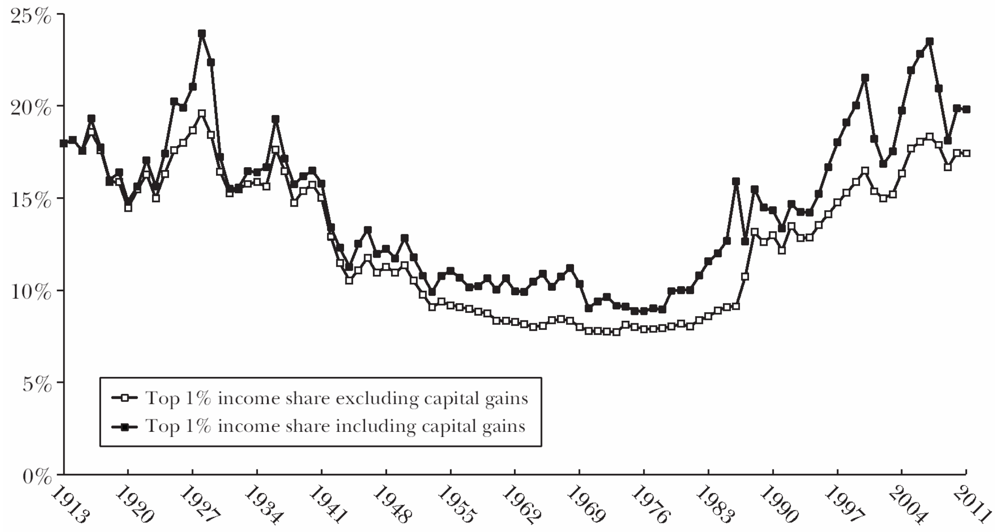
Data on income inequality, as summarized by the share of total income earned by the households in the top percentile of the income distribution, show that inequality decreased between 1913 and the early 1950s, remained stable until the late 1970s, and has then started to increase (fig. 11). Based on this data, inequality would seem a relatively recent phenomenon. Extending the analysis to before 1913 using data on wages, however, shows that inequality also rose during the XIX century. According to Piketty (2014), the picture that emerges is more one of a steady rise of income inequality since the Industrial Revolution, with few periods of stable inequality (in 1870-1913 and 1950-1980), and only one period of decline (in 1914-1949). Thus, it would appear that the only forces that have been able to reduce income inequality have been the shocks that occurred with the two World Wars.

As discussed in Section 5, income inequality is closely related to the skill premium.

[46] Studies focusing on the importance of social capital — defined as the expected collective benefit derived from the way in which individuals interact, cooperate, and trust one another — express a similar view.

[47] As Kuznets (1955) put it, his work was "perhaps 5 per cent empirical information and 95 per cent speculation, some of it possibly tainted by wishful thinking".

Figure 11: Income share of the top 1 percent (1)



(1) Share of total income earned by the households in the top percentile of the income distribution. Annual data, from 1913 to 2011. Source: Alvaredo et al. (2013) and World Top Incomes Database.

By considering different types of workers and sectors, the interpretation of the evolution of inequality that emerges seems to be more complex . First, in the XIX century technical change in the *manufacturing sector* was predominantly "de-skilling": the demand for unskilled workers increased substantially, as the adoption of the steam engine and the factory system favored the substitution of relatively skilled artisans with unskilled operatives. De-skilling, however, did not happen in the *rest of the economy*, where skill upgrading occurred continuously from 1850 to the 1980s: demand for low-skill workers tended to decline, for middle-skill workers it remained constant, and for high-skill workers it increased (Katz and Margo, 2013). Finally, *the last three decades* show a pattern of increased polarization, in which demand for middle-skill jobs is declining, while that for low-skill and high-skill workers is growing. Overall, it appears that wage gaps between different types of workers and different sectors have increased or decreased as technology has evolved, depending on the features of technical change.[48]

Can we reconcile these dynamics with economic theory? In principle, the price mechanism could be a potentially important "re-equilibrating force". As the demand for some inputs — types of workers, natural resources or goods — grows, their price

[48] For example, the profiles of the households in the high and low percentiles of the income distribution have changed substantially over time: the highest-income households were land-owners in the early XIX century, industrial capitalists until the 1980s, and, more recently, they appear to be more evenly distributed across sectors. As Piketty and Saez (2003) put it, "the working rich have now replaced the coupon-clipping rentiers". On the other hand, the lowest-income workers were found first in the agricultural sector and later became proletariats living in industrial cities.

rises, weakening demand. In addition, technological research may concentrate on how to use alternative inputs that are more widely available replacing those that are scarce, or on how to augment the supply of scarce goods, reducing relative price differences.

In a famous study, Rogoff et al. (2001) examined the relative prices of a number of basic goods over a 700-year period.[49] Their results show that product prices have a tendency to revert to a central mean over very long periods. Of course, workers are not commodities, but it may well be that as some workers become increasingly expensive relative to others, research may focus on finding ways to substitute away from these high-cost inputs. In particular, the vast migration from rural areas and from Ireland to English cities during the late XVIII century may have favored the development of the factory system and the replacement of skilled artisans with unskilled workers; later, the expansion of educated labor over the post-war period made it profitable to develop machines complementary to skilled workers (Acemoglu, 2002, Violante, 2008). Today, technological progress may focus on the development of tools and devices that enable education costs to be reduced, raising the supply of skilled workers. The proliferation of Internet-based educational resources, discussed above, is just one example.[50]

Thus, the price mechanism can be a powerful force for promoting equality, but because the adjustment of demand and, especially, supply can take decades, relative wage differentials can temporarily become very wide, fuelling large and persistent income inequalities. It may well be, then, that inequality follows long cycles. Public policies, such as progressive tax systems and the promotion of better and more affordable education and training for unskilled workers, may help attenuate these cycles. Because both market forces and public policies can be quite effective in reducing wage differentials, predictions of income inequality over the next few decades by simple extrapolation from recent trends may turn out to be severely misleading.

7 Conclusion

Recent studies have conjectured that the U.S. economy may soon return to a phase of secular stagnation. There is some consensus on the fact that, in the next 20 to 50 years, the growth of U.S. GDP per capita — equal to an average annual rate of 2.2%

[49] Their study considers barley, butter, cheese, oats, peas, silver, and wheat, covering not only the dynamics of the differences between the prices of the same good in two different countries (the U.K. and the Netherlands) — which is the main focus of the study — but also the dynamics of the differences between the prices of two different goods in the same country.

[50] The use of ICT is now pervasive in the U.S. education system, from students enrollment, to the assignment and submission of homeworks, to the grading and publishing of test results. Computer-assisted scoring, for example, has been used for many years for most large-scale assessment programs, such as the Graduate Management Aptitude Test (GMAT) and the Graduate Record Examination (GRE). More recently, attention is turning to softwares that can scan essays for plagiarism as well as grade them.

— will decrease due to "transitory factors" (mainly hours worked and education). The contribution of these factors, equal to 0.5 percentage points in the post-war period, could become nil in the years ahead, up until 2060, as a result of the retirement of baby boomers, the approaching of a plateau in the years of schooling, and rising relative costs of higher education. But some studies also add that TFP could sharply decelerate, as the effects of ICT seem to have already peaked, TFP has already started to slow down, and no other major breakthrough is in sight. Its contribution to GDP per capita could decline from 1.6 percentage points in 1950-2007 to just 1.0 points over the next few decades. Thus, the lower contributions of TFP and transitory factors imply that the growth of GDP per capita will halve, increasing at a rate of just 1.1%.

The analysis of GDP per capita focuses on the average household, neglecting the fact that, in the last 30 years, income has already been stagnating for the households in the bottom 99% of the income distribution. If inequality keeps growing at the same speed as it has in the last three decades, the incomes of the households in the bottom 99% of the distribution will grow at an annual rate that is 0.5 percentage points lower than the rate recorded for the entire U.S. population. Therefore, if the projections of a 1.1% GDP per capita growth are confirmed, these households' income will increase at a rate of just 0.6%.

The debate on secular stagnation, however, seems to be a cyclical question, which has been raised after all deep and prolonged recessions. Revisiting the arguments made in the past suggests that pessimistic predictions turned out to be wrong neither because they built on erroneous theories or data, nor because they failed in predicting new technologies, but because they underestimated the potential of technologies that already existed. This suggests that we should not make the same mistake today and undervalue the potential effects of the information technology.

Historical experience also suggests a number of issues that should be tackled by future research, including: (*i*) the properties of TFP in the time series and the cross-section of firms, to examine whether there are diminishing returns on the research activity or whether technological progress has instead a "fractal quality", so that the probability that TFP increases does not depend on its level; (*ii*) the extent to which the integration of emerging countries into the global economy can contribute to the growth of the world technology frontier; (*iii*) whether human capital can grow even if the years of schooling and work experience remain constant, by extending the intensive and extensive margins of knowledge; (*iv*) the possible endogeneity of the direction of technical change and the analysis inequality cycles.

Appendix

A The natural interest rate and overlapping generations

Let us consider a growth model in which agents have finite lifetimes. To be analytically tractable, it is useful to assume a constant probability of death p, with higher values of p lowering the expected lifetime.[51] For the sake of simplicity, we assume a log utility function (i.e. $\theta = 1$, in terms of the notation of Section 2), while ρ is still the rate of time preferences.

On the supply side, we assume a Cobb-Douglas production function with constant returns to scale, in which capital and labor are inputs, $\alpha \in (0, 1)$ is the share of capital and $\delta > 0$ the rate of depreciation of the capital stock. We further assume that total population grows at a rate $n \geq 0$ and exogenous labor augmenting technological progress at a rate $x \geq 0$. Finally, a crucial assumption concerns the behavior of labor productivity over workers' lifetime. Following Blanchard (1985) we assume that it declines with age at the rate ω and the wage declines accordingly. This feature of the model makes it possible to obtain inefficient oversavings, lowering the NRIR.

To show the dynamics of the model, it is convenient to transform the variables in units of effective labor. Thus, let $\hat{c} = C/AL$ and $\hat{k} = K/AL$ denote, respectively, consumption per effective worker and capital per effective worker. These variables are constant in steady state, while the per capita variables C/L and K/L grow at the constant rate of exogenous progress, x, while C and K grow at the rate $x + n$.

The model is summarized by the following set of differential equations:

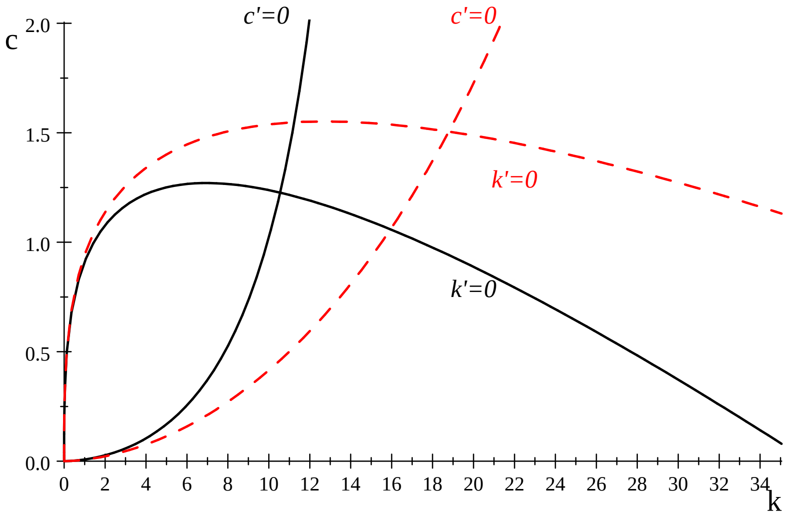
$$\hat{k}' = A\hat{k}^{\alpha} - \hat{c} - (x + n + \delta)\,\hat{k} \tag{10}$$

$$\hat{c}' = \left[\alpha A\hat{k}^{\alpha-1} - \delta - (\rho + x - \omega)\right]\hat{c} - (p + n + \omega)(p + \rho)\,\hat{k}, \tag{11}$$

where the "prime" denotes a derivative with respect to time. Equation 10 is a standard capital accumulation formula (as in infinite-horizon growth models), while the Euler equation (11) has two special features. First, it yields a "generation replacement effect": in every instant, people who have accumulated wealth die and other people, who do not have any wealth, are born, and this "replacement" lowers aggregate consumption. To see by how much, note that replacement occurs with probability $p + n$ and that average consumption for a worker is $(p + \rho)\,\hat{k}$. Thus, generational turnover reduces aggregate consumption by $(p + n)(p + \rho)\,\hat{k}$.

[51] In the absence of bequest motives and precluding the possibility of a negative bequest, all agents take out an insurance in which the insurance company receives the entire wealth in the case of death and pays a share p of wealth if the agent survives.

Figure 12: Effects of a reduction in x (1)



(1) The curves $k' = 0$ ($c' = 0$) show the locus of $(\hat{k}, \hat{c})$ such that the growth rate of $\hat{k}$ ($\hat{c}$) is zero. The two solid black lines (dashed red lines) are drawn under $x = 2\%$ ($x = 0\%$).

Second, the assumption of declining productivity throughout lifetimes affects consumption growth in two different ways. A higher rate of productivity decline (i.e. a larger ω) raises consumption as the new generations enter with higher-than-the-average wages. For larger ω, however, the generation replacement effect (which lowers consumption) is also larger.[52]

The balanced-growth condition $\hat{c}' = 0$ implies that:

$$\hat{c} = \frac{(p + n + \omega)(p + \rho)}{\underbrace{\left(\alpha A \hat{k}^{\alpha-1} - \delta\right)}_{r} - (\rho + x - \omega)} \hat{k}$$

Thus, non-negative consumption requires $r \geq \rho + x - \omega$, which means that the NRIR can be negative if ω is sufficiently large.

Let us now consider the standard calibrations of the parameters:

$$\rho = 0.02 \quad \delta = 0.05 \quad n = 0.01 \quad A = 1 \quad \alpha = 0.3 \quad p = 0.01 \quad \omega = 0.05\ .$$

Assume also that the rate of technological progress, x, declines from 2% to 0. Figure 12) shows that the implied interest rate at the initial steady state (the intersection of the two solid black lines) is $r^* = 1\%$; after the decline in x, the interest rate in the

[52] Alternatively, one can concentrate on the direct effect of the assumption of declining wages, which subtracts from ρ and therefore lowers the effective rate of time preferences. This encourages capital accumulation: if labor income accrues early in a worker's lifetime, it will lead to more savings early in life and thus to a larger aggregate capital stock.

new steady state (the intersection of the two dashed red lines) becomes $r^{**} = -0.6\%$.[53] Given the above parameters, how large should ω be in order to obtain an equilibrium interest rate equal to -2%? Simple algebra shows that, even if the rate of technological progress is zero, the rate of wage decline should be very large, in the order of 20% *per year*.

Thus, the fact that people retire and labor income declines may lead to inefficient capital accumulation, as the equilibrium interest rate is lower than the sum of the exogenous rates of TFP and population growth. A negative NRIR, however, obtains only under implausibly steep declines of wages through the lifetime.[54]

[53] A decrease in x shifts the (k'=0)-curve upward and the (c'=0)-curve rightward, raising the steady-state capital stock and reducing the equilibrium interest rate. The effect on aggregate consumption is, instead, ambiguous.

[54] In the case of inefficient overaccumulation of capital, an important policy implication regards the effect of fiscal policy. With finite lifetimes (and without altruism) taxes introduced at different times are levied on different sets of people and, therefore, government financing affects consumption choices. Examples can be built, in particular, in which an increase in public spending and an offsetting increase in taxes reduce the steady-state capital stock and raise the natural real interest rate.

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