The Future of U.S. Economic Growth

By John G. Fernald and Charles I. Jones*

Arguably the most important fact of the last century is the steady rise in living standards throughout much of the world. Will this rise continue into the future? We discuss what modern growth theory has to say about economic growth in the United States over the next 25 to 50 years.

I. The Facts

Figure 1 shows GDP per person for the United States between 1870 and the present. The stability of the growth rate is remarkable and surprising, with GDP per person lying close to a linear time trend with a slope of just under 2 percent per year. Even the Great Depression was a persistent but not permanent deviation. A tempting conclusion from this figure is that a good guess for future growth is around 2 percent per year.

Despite the impressive fit of a linear trend, growth has at times deviated noticeably from a 2-percent baseline. Visually, for example, it is clear that growth was slower pre-1929 than post-1950. Between 1870 and 2007 (to exclude the Great Recession), growth was 2.03 percent per year. Before 1929, growth was a quarter point slower (1.76), while since then it has been a quarter point faster (2.23).[1] Growth from 1950 to 1973 was faster still (2.50), but then slowed markedly until 1995 (1.82).

The U.S. experience may also understate uncertainty about the future, since other countries have often seen level as well as growth rate changes. Early in the 20th century, for example, the U.K. was substantially richer than the United States; by 1929, the situation was reversed.

Japans experience since 1990 — and the financial crisis and Great Recession more recently — raises a related concern. Standard growth theory implies that a financial crisis should not have a long-term effect on income per person: if the rate of time preference and the other parameters of the economic environment are unchanged, the economy should eventually return to its original steady state. This insight is strongly supported by the U.S. experience following the Great Depression, as shown in Figure 1. Despite the large negative shocks of 1929 and the 1930s, the Great Depression was, in the end, temporary — the economy returned to its balanced growth path. However, this logic has failed dramatically in the case of Japan after 1990. Japanese GDP per capita peaked at 86% of the U.S. level in 1995 and has since fallen to 75%. This observation, which is not easy to understand in terms of the theory we lay out next, is an important cautionary reminder about projecting U.S. growth over the next several decades.

II. Accounting with Modern Growth Theory

We now turn to a version of growth accounting suggested by modern growth theory. Traditional growth accounting, following Robert M. Solow (1957), calculates TFP as a residual. Modern growth theory explains that residual in terms of economic forces.

We discuss a semi-endogenous growth model in which long-run growth arises from the discovery of new ideas. The nonrivalry of ideas leads to increasing returns, the key point of Paul M. Romer (1990). Income per person then depends on the total number of ideas, not on ideas per person. Adding one new idea potentially benefits everyone, regardless of the size of the economy, because the idea is not depleted from use. In contrast, adding one more tractor or school building benefits only a few people. Hence, growth of income per person is tied to growth of ideas. Idea growth, in turn, naturally depends on growth in the number of people looking for new ideas. This most directly equals growth in the number of researchers, but, ultimately, it is tied to population growth. Scale (e.g., the popu-

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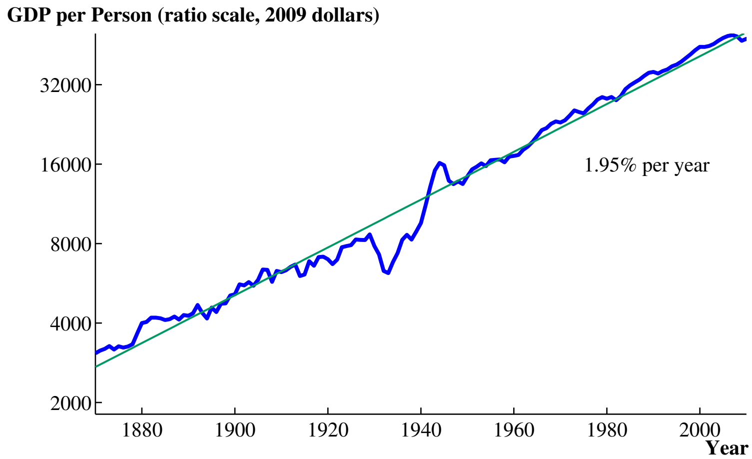
[1] The faster post-1929 growth partly reflects changes in measurement: better price deflators and including some intellectual investments as final output.

FIGURE 1. U.S. GDP PER PERSON



Note: Data for 1870 to 1929 are from Angus Maddison (2008). Data for 1929 to 2012 are from the Bureau of Economic Analysis

lation of countries producing new ideas) matters for idea-based economies.

Figure 2 summarizes the resulting growth accounting from Charles I. Jones (2002), which we have updated to the period 1950–2007. The model features physical capital, human capital, and a decision about how much research to undertake. Thus, the model incorporates key insights of modern growth theory. The equation and implementation assume growth rates are constant over time, which we argued earlier is a reasonable approximation for the U.S. economy. Importantly, this is not necessarily (and, we argue below, is not) the balanced-growth path.

Output per person, y, depends on four terms. First is the capital-output ratio, as in Robert M. Solow (1956). Second is human capital per person, as in Edward F. Denison (1962) and Robert E. Lucas (1988). Third is research intensity, the investment rate that applies to the hunt for new ideas (here, the share of population that works as researchers), as emphasized by Paul M. Romer (1990), Philippe Aghion and Peter Howitt (1992), and Gene M. Grossman and Elhanan Helpman (1991). Fourth is the number of people in the economy, as in the semi-endogenous growth models of Charles I. Jones (1995), Samuel S. Kortum (1997), and Paul Segerstrom (1998). The last two terms, which correspond to TFP, constitute the stock of ideas. That stock is inferred from the "flow" investment terms (research intensity and population).

As the figure shows, the 2 percent annual growth in labor productivity largely came from rising human capital (0.3 p.p. per year, about a sixth of the total) and rising research intensity in the advanced countries of the world (1.2 p.p., or 61 percent of the total).[2]

The contribution of human capital is easy to understand. The educational attainment of the working-age population has been rising about one year per decade. A Mincerian return to education of 6 percent would imply about 0.6 percentage points extra growth each year. In the accounting above, we use the BLS measure of labor composition, which grows more slowly. Additional aspects of labor quality beyond education, such as demographics, presumably explain the difference.

Figures 3 shows data on educational attainment, by birth cohort rather than the cross-section of workers. After 1950, the rise in education slows markedly and has ceased for the most recent cohorts. Nothing in the model requires this — educational attainment could rise with life expectancy and could even rise faster than life expectancy for a long time. However, educational attainment in the data does slow. In the future, one can reasonably expect a reduced contribution from education and, other things

[2]These numbers differ somewhat from Charles I. Jones (2002), not because of the change in sample period, but because we are using the BLS labor quality term to measure human capital, whereas Jones (2002) used only educational attainment; see the next paragraph.

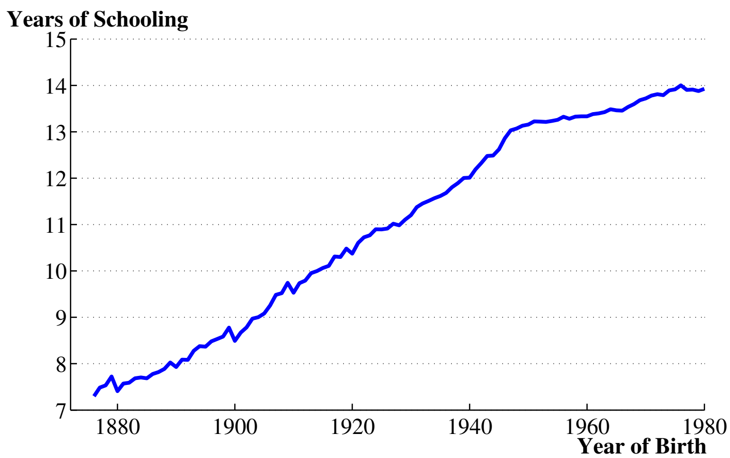
FIGURE 2. GROWTH ACCOUNTING WITH MODERN GROWTH THEORY

$$y^* \approx \left(\frac{K}{Y}\right)^{\beta} \cdot h \cdot (\text{R\&D intensity})^{\gamma} \cdot L^{\gamma}$$

	Solow	Lucas	Romer/AH/GH	J/K/S
2.0	0.0	0.3	1.2	0.5
(100%)	(0%)	(16%)	(61%)	(23%)

Note: Growth rates and shares of overall growth show the contribution of each term in the equation to growth in U.S. GDP per hour between 1950 and 2007. See Charles I. Jones (2002) for the methodology; a spreadsheet available on the authors' web page contains the details.

FIGURE 3. EDUCATIONAL ATTAINMENT BY BIRTH COHORT



Source: Claudia Goldin and Lawrence F. Katz (2008).

equal, slower income growth.

In sum, the accounting implies that growth over the past 50 years largely reflected transitory factors. The rise in educational attainment is already slowing, and the fraction of the labor force engaged in research cannot growth forever. Taken literally, only the scale-effects term — equal to 0.5 pp, or 23 percent of growth — generates sustainable long-run growth. Even this term could itself be slowing along with fertility rates. We do not know *when* this long run will occur, but Figure 2 implies that future growth might be significantly lower than over the past half century.

III. Diminishing Returns, Robots, and China

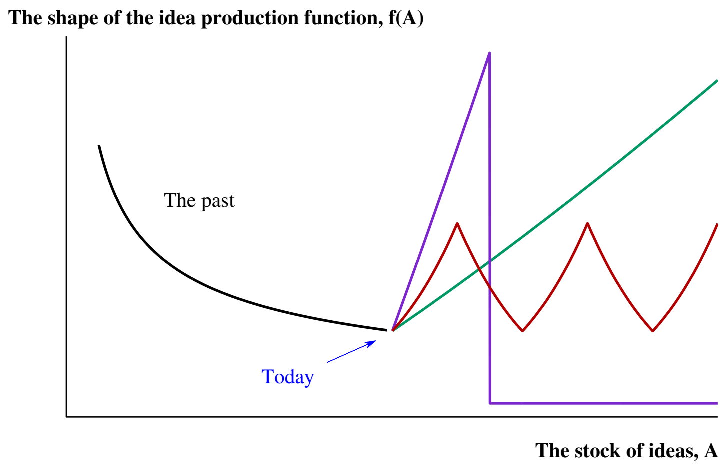
Will growth, in fact, slow sharply in the coming decades? The accounting outlined in the previous section implicitly depends on some assumptions worthy of further consideration, one related to the shape of the idea production function and the other involving the growth of inputs into research. Specifically, underlying the parameter γ in Figure 2 is the production function for new ideas. That function typically has a form like:

$$\dot{A} = Rf(A) = \beta R A^{\phi} \quad (1)$$

where R is the number of researchers, A is the stock of ideas, and $\dot{A}$ is the flow of new ideas produced over time.

Restricting $f(A)$ to be a power function is required for balanced growth but still allows flexibility. For example, Charles I. Jones (2002) argues that historically, $\phi < 0$ may be reasonable. That is, as more ideas are discovered, it can become harder and harder to discover the next new idea — a "fishing out" argument. Sim-

FIGURE 4. ALTERNATIVE FUTURES?



Note: The shape of the idea production function for future levels of A need not look like it has in the past.

ilarly, Tyler Cowen (2011) and Robert J. Gordon (2012) argue that we may have "cherry picked" the most easily-discovered and important ideas already, perhaps implying slower growth in the future.[3] Note that diminishing returns to the idea production function in equation (1) is consistent with balanced growth even if ϕ is negative. Though *proportional* improvements in the stock of ideas gets harder and harder, balanced growth can still occur because of exponential growth in the number of researchers, R. The difficulty of making proportional increments is offset by growing efforts to push the frontier forward.[4]

Of course, while restricting $f(A)$ to be a power-function is convenient and tractable, it might not be realistic. Moreover, the shape of $f(A)$ we have seen in the past might not be a reliable guide to the shape of $f(A)$ at higher (future) levels of A. For example, consider the alternative paths shown in Figure 4. Here, the idea production function of the past exhibits diminishing returns — it gets harder and harder to discover new ideas. This path might continue into the future. Alternatively, we could reach an inflection point, after which it becomes easier and easier to discover new ideas. Or this could be true for awhile, but then maybe there are no additional new ideas to discover and $f(A)$ drops to zero. Or perhaps there are waves of good and bad periods corresponding to "general purpose technologies." Each alternative implies very different paths for future economic growth.

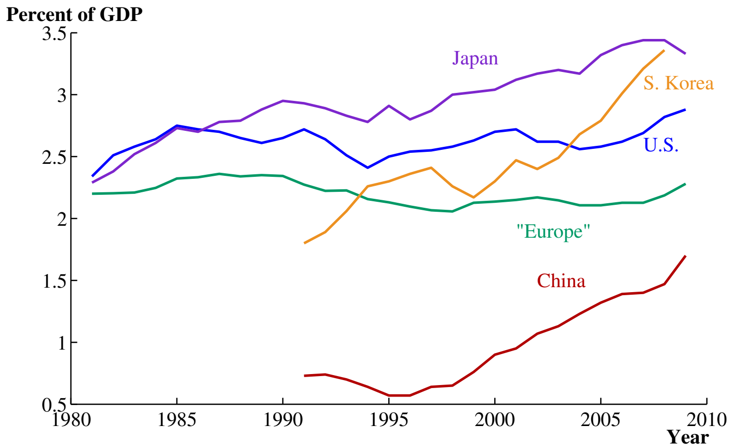
A second important consideration is growth in research inputs, R. In the accounting above, R has been growing faster than population. This cannot continue forever, pointing towards slower future growth. But the number of relevant researchers might grow for a long time, and new research technologies might allow computers and robots to replace labor.

In terms of the number of researchers, developing economies are becoming richer and increasingly contribute to pushing the technological frontier forward. Figure 5 shows that South Korea and China exhibit particularly rapid growth in research spending — faster than even their already rapid GDP growth rates. China and India together have more than 1/3 of the worlds population, so these economies could contribute substantially to future technological progress, far beyond what has probably been a negligible contribution over the last 50 years. Richard B. Freeman (2009) points out that in 1978, China produced almost no Ph.D.s in science and engineering, but by 2010, they were producing 25 percent *more* than the United States. How many future Thomas Edisons and Steve Jobses are there in China and India, waiting to realize

[3] As venture capitalist Peter Theil puts it, "We wanted flying cars, instead we got 140 characters."

[4] As an aside, consider the growth implications of the Great Recession. A reduction in research effort could have a persistent if not permanent effect on productivity. However, the slowdown in real R&D spending appears modest relative to previous recessions so this argument does not seem quantitatively persuasive. John Fernald (2012) argues that productivity did slow, but prior to the Great Recession.

FIGURE 5. R&D EXPENDITURES AS A SHARE OF GDP



Source: NSF Science and Engineering Inicators, 2012, Appendix Table 04-43. "Europe" is the unweighted average of the numbers for France, Germany, and the United Kingdom.

their potential?

Even more speculatively, artificial intelligence and machine learning could allow computers and robots to increasingly replace labor in the production function for goods. Erik Brynjolfsson and Andrew McAfee (2012) discuss this possibility. In standard growth models, it is quite easy to show that this can lead to a rising capital share — which we intriguingly already see in many countries since around 1980 (Karabarbounis and Neiman, 2013) — and to rising growth rates. In the limit, if capital can replace labor entirely, growth rates could explode, with incomes becoming infinite in finite time.

For example, drawing on Joseph Zeira (1998), assume the production function is

$$Y = AK^{\alpha}\left(L_1^{\beta_1} L_2^{\beta_2} \cdot \cdot L_n^{\beta_n}\right)^{1-\alpha}. \tag{2}$$

Suppose that over time, it becomes possible to replace more and more of the labor tasks with capital. In this case, the capital share will rise, and since the growth rate of income per person is $1/(1-$ capital share $)\times$ growth rate of A, the long-run growth rate will rise as well.[5]

[5]Alternatively, consider the standard capital accumulation equation with Cobb-Douglas production: $\dot{K} = sA^{\sigma}K^{\alpha}L^{1-\alpha} - \delta K$. If the labor input can be replaced entirely by capital, this equation becomes $\dot{K}/K = sA^{\sigma} - \delta$. As knowledge accumulates, the growth rate of K rises exponentially. Notice that the nonrivalry of ideas is at the heart of this result.

IV. Conclusion

Budget projections by the CBO use a neoclassical growth model where TFP growth is typically assumed to equal its post-1948 average. David M. Byrne, Stephen D. Oliner and Daniel E. Sichel (2013) analyze recent trends in semiconductors to obtain insight into the current shape of the idea production function and undertake projections. But modern growth theory suggests that such projections are at best a local approximation. The roughly constant growth of the past century and a half does not mean the U.S. is on a steady-state path, and the past — even the recent past — could be a poor guide to the future.

Our analysis suggests several key considerations. First, growth in educational attainment, developed-economy R&D intensity, and population are all likely to be slower in the future than in the past. These factors point to slower growth in U.S. living standards. Second, a counterbalancing factor is the rise of China, India, and other emerging economies, which likely implies rapid growth in world researchers for at least the next several decades. Third, and more speculatively, the shape of the idea production function introduces a fundamental uncertainty into the future of growth. For example, the possibility that artificial intelligence will allow machines to replace workers to some extent could lead to higher growth in the future. Finally, other considerations we have not had space to address could impact future growth, including the rise in income inequality, climate change, and the systematic shift of the economy toward health care.

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