Is Technological Progress a Thing of the Past?

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A new wave of techno-pessimism is upon us:

The new technopessimist interpretation (for instance Robert Gordon) says that the low-hanging fruits of invention have been picked.

Future inventions, we are told, will not have nearly as radical an effect as before.

For that reason, innovation will not be powerful enough to counter other economic “headwinds” and annual GDP growth will slow down to a trickle.

Is the world running out of ideas?

Perhaps the relatively "easy" inventions that have changed our lives have been picked: running water, chlorination, electricity, air conditioning, antibiotics etc?

But scientific progress in the past decades has been as exciting as ever. Major advances in many fields, from astronomy to material science to molecular genetics and immunology.

Will these advances matter to the economy? Will they provide a tornado-strength tailwind that will more than overcome the headwinds?

We may want to reflect on what is known as "Amara's Law"

"We tend to overestimate the effect of a
new technology in the short run
and underestimate the effect in the long run."

Roy Amara,
Past president of
The Institute for the Future.

Historical point of view.

What can an economic historian bring to the discussion of the long run?

From a purely technological point of view, if the patterns of the past hold (a big if), there is some reason to expect the rate of technological change to accelerate over the next decades, although it would be foolhardy to be more specific than that (and even more to try to predict the rate of productivity growth).

Historically, progress in S&T has been a function of well-understood factors

Progress_t (however measured) = F (X_{t-n}, Y_{t-m}, Z_{t-k}.... ε).

My method: identify some of the independent variables of the past. Assess their values and use *their current values* to form some reasonable expectation about the future. Unfortunately we don't know what the R^2 is, nor what the exact coefficients are and whether they are time-invariant. The lag structure is clearly changing. Moreover, there are omitted variables correlated with the ε's.

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First exogenous variable: Diversity and Competition

Scientific and Technological progress in the age of the Industrial Revolution and beyond were heavily stimulated by the constant competition between nations (contemporaries called it ‘emulation’) that had to keep up with one another (“Race to the top” and “Sputnik effect”).

According to that interpretation, the political fragmentation and the religious and cultural pluralism of Europe were a key to its success in the 18th and 19th centuries (Jones, 1981; Baechler, 2006; Karayalcin, 2008; Mokyr, 2015).

This was recognized at the time of the Industrial Revolution:

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Europe is now divided into twelve powerful, though unequal, kingdoms, three respectable commonwealths, and a variety of smaller, though independent, states: the chances of royal and ministerial talents are multiplied, at least, with the number of its rulers . . . The abuses of tyranny are restrained by the mutual influence of fear and shame; republics have acquired order and stability; monarchies have imbibed the principles of freedom, or, at least, of moderation; and some sense of honour and justice is introduced into the most defective constitutions by the general manners of the times. ***In peace, the progress of knowledge and industry is accelerated by the emulation of so many active rivals****; in war, the European forces are exercised by temperate and undecisive contests."* (Gibbon, 1789, V.3, p.636)

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So what does this model predict for today?

The world is more pluralistic and competitive than ever. Globalization does NOT imply that competition between 5-6 major blocks is not as intense as it was in the seventeenth century (but it is to be hoped that it will not end the same way in a series of destructive wars).

All participants realize that unless they keep up with best-practice science and technology, they will fall hopelessly behind in the global competition. Hence their concerns with STEM education, PISA scores, and the emphasis on Global IPR's.

Second exogenous variable: incentives

In the past, incentives have always been critical to the progress of knowledge.

Two kinds of incentives matter here. First, *positive* inventives: given the well-known lack of appropriability of knowledge, how do we reward the Galileos and Lavoisiers and Plancks of this world for their useful insights? Second, *negative* incentives: how do we prevent vested interests and reactionary powers to prosecute innovators for "heresy" or "playing God"?

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In the past Europe found a solution to the incentive problem:

- **Positive**: Rewards were based on reputations. People wanted peer recognition because it was correlated with patronage, but also for its own sake. This led to the emergence of “open science” (David and Dasgupta, 1992). Later on it the reward system came to rely in part on IPR’s (= patents), which were globalized after 1880 – but that applied to inventions, not scientific breakthroughs.

- Negative: Tolerance and progressive institutions made prosecution of “deviant” thinkers increasingly less likely in the Age of Enlightenment. Still, even today many people resist some innovations on philosophical rather than practical grounds (e.g. GMO’s, cloning, nuclear power).

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Yet, on the whole, today in our age we richly reward and honor successful inventors and scientists.

Although most innovators capture only a small portion of the "social surplus" they create, we tend to respect and reward them. And IPR's, despite everything that is wrong with them (a lot) still constitute a strong *ex ante* incentive for innovators. But they also use other means: secrecy, first-mover advantage, prizes.

In "enlightened" countries, we rarely prosecute someone for sacrilege or blasphemy. Which is why the industrialized nations will continue to engage in R&D. Countries in which thinking outside the box can get you in trouble with religious or political authorities or vigilantes will not be innovative --- but as long as it is happening *somewhere* that may not matter all that much.

Third exogenous variable: technology provides science with its tools

The low-hanging fruits of science have (perhaps) mostly been picked. But science builds taller and taller ladders.

“Artificial Revelation” --- the ability to create tools that allow us to observe phenomena that nature did not mean us to observe and do things that nature did not mean us to do (Price, 1984).

In that way, technological progress stimulates discoveries, that then in turn allow further innovation. In this fashion, technology pulls itself up by the bootstraps, via improved scientific understanding.

It was thus in the past:

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Scientific progress in the past was driven by better tools and instruments.

The best-known examples are of course “the great trio” of the telescope, the microscope, and the barometer, all developed during the early seventeenth-century. These three instruments played a big role in the Scientific Revolution. But there are many others.

Let me give you a few lesser-known examples from the era before and during the Industrial Revolution to drive the point home.

Boyle’s famous air pump

Robert Boyle’s famous air pump, built in the late 1650’s, which showed once and for all that *contra Aristotle*, nature did not abhor a vacuum, and thus paved the road for atmospheric (steam) engines.

Volta's "pile" (1800)

Volta's battery provided chemists with a new tool, electrolysis, pioneered by Humphry Davy. He and other chemists were able to isolate element after element, and fill in much of the detail in the maps whose rough contours had been sketched by Lavoisier and Dalton.

And in medicine:

Joseph J. Lister (father of the famous surgeon), inventor of the achromatic microscope that minimized both chromatic and spherical aberration.

This made it possible eventually for Pasteur, Koch and others to demon-strate that infectious diseases were directly linked to identifiable microorganisms.

- What about 2015?

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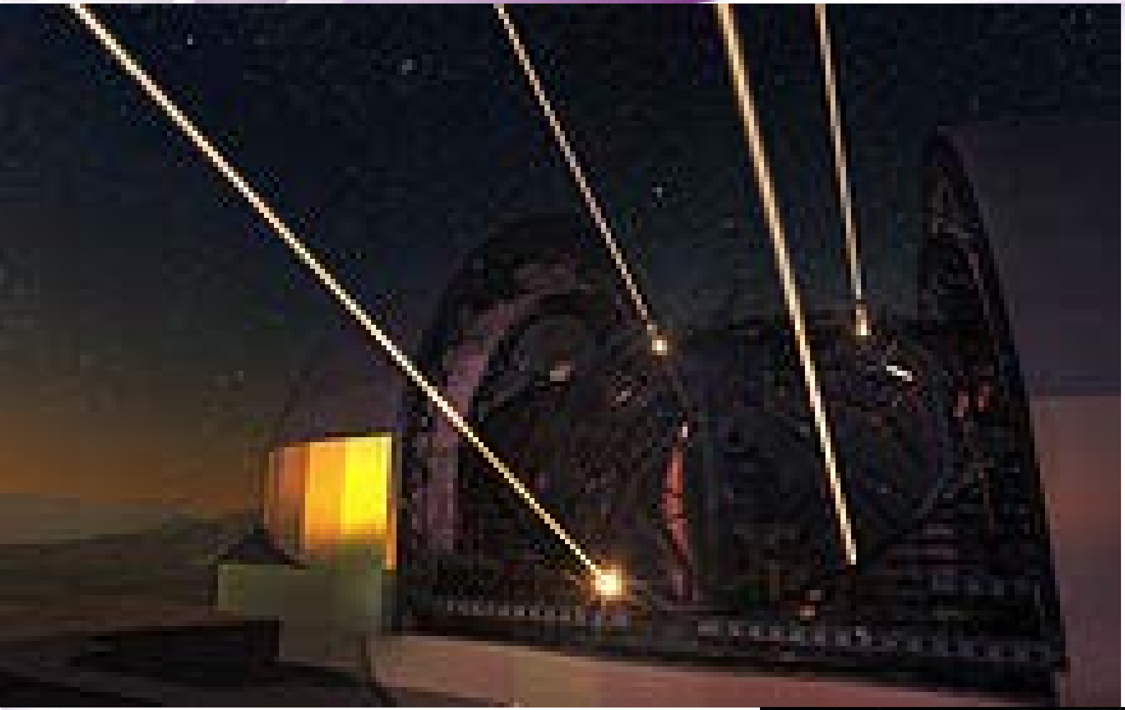
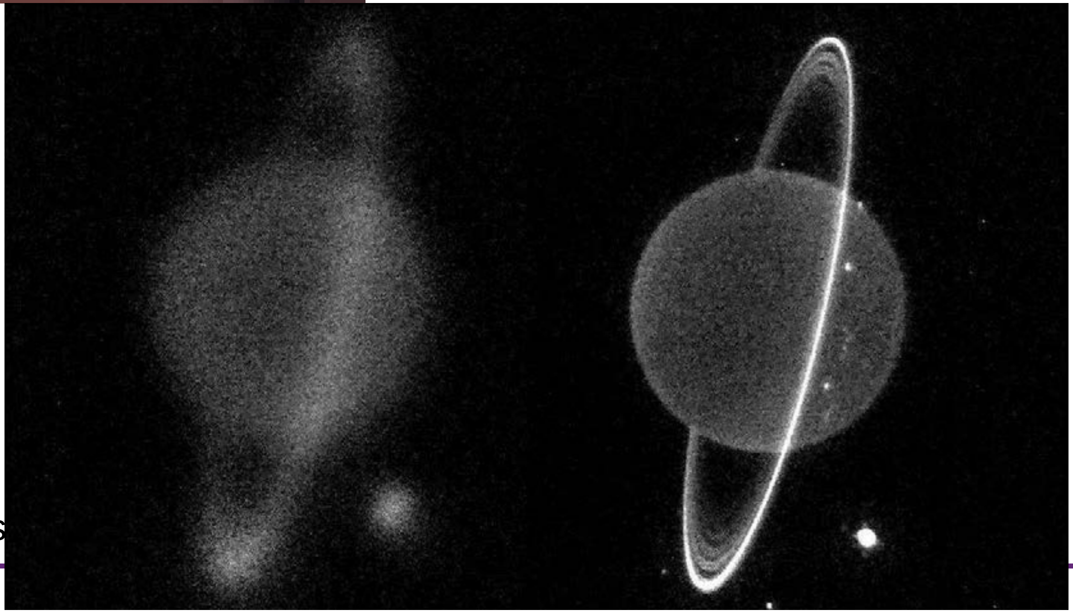
Galileo never had this:



Artist’s impression of the European Extremely Large Telescope deploying lasers for adaptive optics

Images of the planer Uranus, standard telescope and adaptive optics telescope



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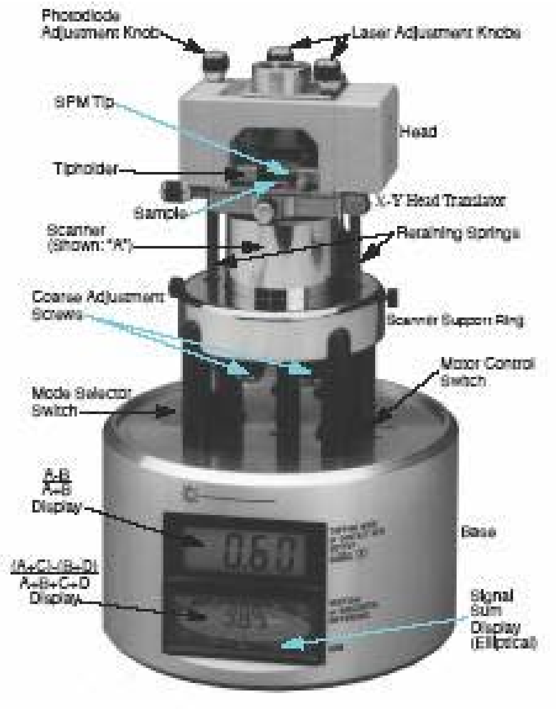
Neither did Pasteur have this:



Betzig-Hell type of stimulated emission depletion (STED) microscope

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And the most revolutionary:

Stanley Cohen and Herb Boyer were the first to successfully insert the genetic material from one species into another to bring about hetero-logous gene expression.

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Finally, of course, the computer

It is hard to think of a single field of research that has not been transformed by computers.

The real question often seems to be: what did we ever do *before* it?

My interest here is not in what the digital revolution does for productivity directly, but rather indirectly through its effect on science.

Computers allow research hitherto impossible

Turbulence: the English applied mathematician Horace Lamb sighed in 1932 that “I am an old man now, and when I die and go to heaven there are two matters on which I hope for enlightenment. One is quantum electrodynamics, and the other is the turbulent motion of fluids. And about the former I am rather optimistic.”

High powered computers allow the direct numerical simulation of complex (Navier-Stokes) equations that do not have closed form solutions.

This work is just starting, and we need much more powerful computers to make progress.

Perhaps just as promising: material science

- Materials have historically been at the heart of economic civilization. Hence terms such as the "iron age." Historically, progress here has been always the result of a combination of tedious and inefficient "trial and error" and serendipity (classic example: William Perkins discovery of aniline purple in 1856 and Bessemer steel the same year).
- We now can simulate the quantum chemistry equations that define the properties of materials using high-throughput supercomputers to experiment with materials having pre-specified properties *in silico*.

[This does not mean we do not need to test new materials altogether, but it vastly shortens the testing time to a few months (by comparison, lithium ion batteries invented by Sony in 1991 took 20 years to develop) and increases the options by orders of magnitude.]

- What is certain is that every field of human inquiry, from molecular genetics and astrophysical dynamics to economic history and French medieval poetry relies on computers.

Fourth exogenous variable: focusing devices

- Science and Technology advance most rapidly when the world poses them with well-defined problems that are within the capabilities of that society (unlike some advances that are at first “a solution looking for a problem.”)
- It involves realizing that solving them will enhance social welfare significantly. Rosenberg’s idea of “focusing devices.”

The eighteenth-century Industrial Revolution did exactly that. It faced a number of well-defined problems:

1. How to pump water out of coalmines.
2. How to spin high quality cotton yarn inexpensively.
3. How to turn pig iron into wrought iron.
4. How to fight smallpox.
5. How to solve the “longitude at sea problem.”

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Of course, only the problems that were in their reach were solved. Eighteenth-century engineers could not build airplanes or submarines, tame and harness electricity, and even cheap steel defied them for a long time.

The twentieth century did the same for a host of problems, from polio vaccines to Project Manhattan

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Similarly, in our own age: many well-defined problems

1. Global warming and climate change.
2. Ocean acidification (global warming's 'evil twin')
3. Desertification and water scarcity.
4. Multidrug resistance to antibiotics.
5. Energy storage and transmission.
6. Digitally-driven mass-customization
7. Fish and seafood depletion.
8. Growing obesity.
9. Mental deterioration with age.
10. Information overload.

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To sum up:

- We are not like the late Roman Empire or Qing China, about to languish into an age of decline to be followed possibly by chaos and barbarism.
- Technological progress is still remote from reaching a ceiling or even diminishing returns (and may never do so).
- Economic growth, in an economically meaningful way (if not necessarily in a traditional NI accounting way) will continue.

- The Digital Age will be to the Analog Age what the iron age was to the stone age.

- And we can’t even imagine what the Post-digital Age will look like. No more than Archimedes could imagine CERN.

Thank you