Is Technological Progress a Thing of the Past?

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A new wave of techno-pessimism is upon us:

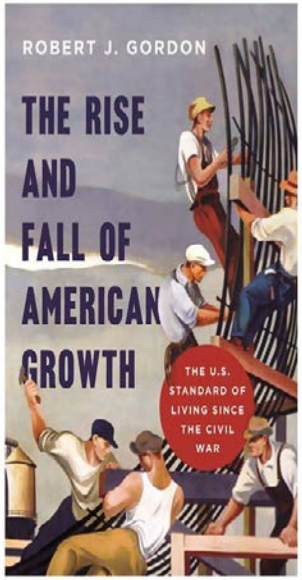
The new technopessimist interpretation (for instance Robert Gordon) says that the low-hanging fruits of invention have been picked.

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.

This is a supply side argument; there is also a demand-side argument known as “secular stagnation” associated with Alvin Hansen and recently revived by Larry Summers.

I will address only the supply story, which is more interesting and has more scholarly substance.



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Is the world running out of ideas?

Perhaps the relatively "easy" inventions that have changed our lives have been picked: running water, water chlorination, the Haber-Bosch process, electricity, air conditioning, antibiotics etc? [note: what seems easy to us may not have been easy at the time!]

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 Gordon's "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.

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Historical point of view.

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

Here is my argument: 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).

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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 impact and "plug in" *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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Here is why some of the material in my book may be relevant:

This is what I do in the book: I look at the factors that account for the technological "take-off" in Europe before 1700 (and sometimes after). I argue that the cultural and institutional factors that explain Europe's subsequent economic growth and flourishing were laid down between 1500 and 1700.

We can then see to what extent these factors hold for our own world.

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 (eighteenth-century 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)

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 nor that the nation state is passé (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.

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What it also means that it is difficult for nations that for one reason or another are reluctant to adopt or trying to suppress certain new techniques (e.g. GMO's in Europe or stem cell therapies and cloning research in the US), will be under serious pressure to adopt them.

In a competitive world, no single polity can suppress innovation and if they refuse to adopt it, they will fall behind in some dimension.

(China recently made an about-face on GMO crops).

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In today's globalized world

- As long as scientific and/or technological progress are happening *somewhere,* technological reactionary policies may not matter all that much.
- The difference between the early modern period and our time is speed: in those days it could take years if not decades for pathbreaking inventions to disseminate. Now it is instantaneous.

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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 early modern period Europe found a solution to the incentive problem:

- **Positive**: Rewards were based on reputations. People wanted peer recognition because it was correlated with patronage jobs, but also for its own sake. Peer recognition meant above all the need for the communication and distribution of intellectual innovations.

Maturing of the concept of “priority rights” --- credit for but no profit from intellectual innovations.

This led to the emergence of “open science” between 1500 and 1700 (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 only to inventions, not to scientific breakthroughs. Yet what really drove progress was the advance in basic and applied science (“propositional knowledge”).

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Negative incentives: Tolerance and progressive institutions made the prosecution of "deviant" thinkers increasingly less likely in the Age of Enlightenment. Indeed, the Enlightenment meant in large part precisely *the contestability* of all accepted knowledge and conventional wisdom, no matter how sacrosanct.

Today this system is still in place. Despite some wrinkles and some threats from the inevitable conservatism of the peer review system, contestability is still functional and thriving today.

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Today in our age we richly reward and honor successful scientists.

Although most innovators capture only a small portion of the "social surplus" they create, we tend to respect and reward them.

The patronage system is alive and well in universities, funding agencies, and research institutions, and while it is not perfect, the fundamental reward system still works, from Nobel prizes down.

And the patent system, despite everything that is wrong with it (a lot) still constitutes a strong *ex ante* incentive for innovators.

But innovators also use other means: secrecy, first-mover advantage, prizes.

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:

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.

Here are 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.

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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.

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And in medicine:

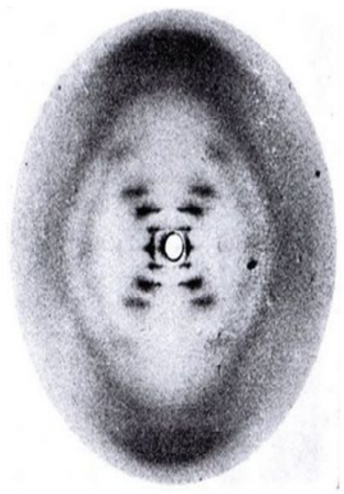
Joseph J. Lister (father of the famous surgeon), inventor of the achromatic microscope that minimized both chromatic and spherical aberration.

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

In more recent times

The most famous discovery in the biological sciences in the twentieth century, the discovery of the structure of DNA by Watson and Crick in 1953, was made possible by x-ray crystallography.

This technique was discovered much earlier (1912) by Max von Laue, but it took the skills of Rosalind Franklin to apply it to the structure of DNA.



Diffraction Pattern or B-DNA

In May 1952, Rosalind Franklin took beautiful X-ray diffraction patterns of pictures of B-form DNA . The X-pattern is indicative of a helix!!

The bases are 0.34 nm apart; there are ten nucleotides per turn; each turn has a rise of 3.4 nm; the diameter of the helix is 2 nm.

This pattern is consistent with the model that Watson and Crick built.

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- What about 2016?

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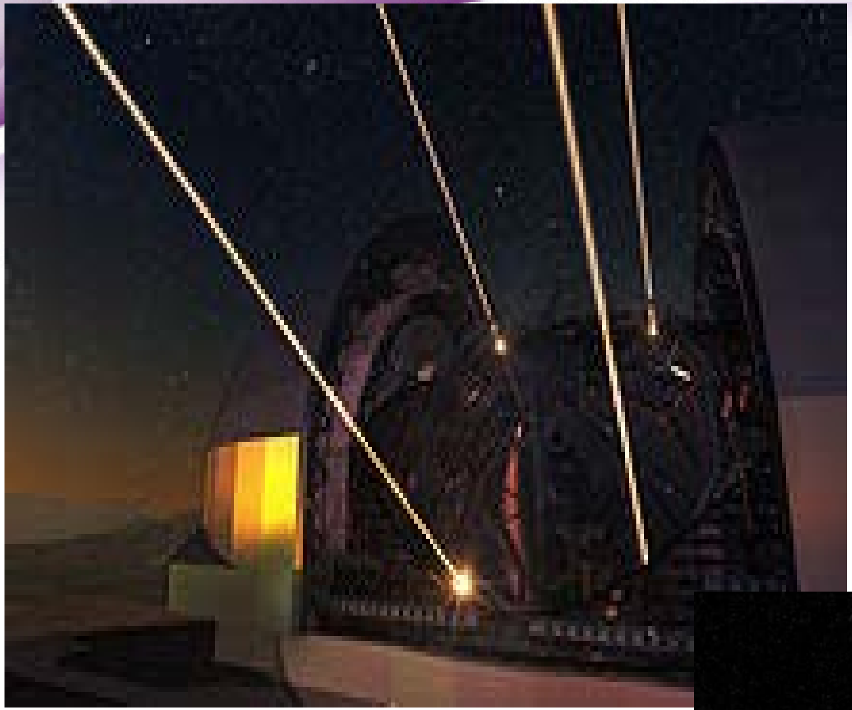
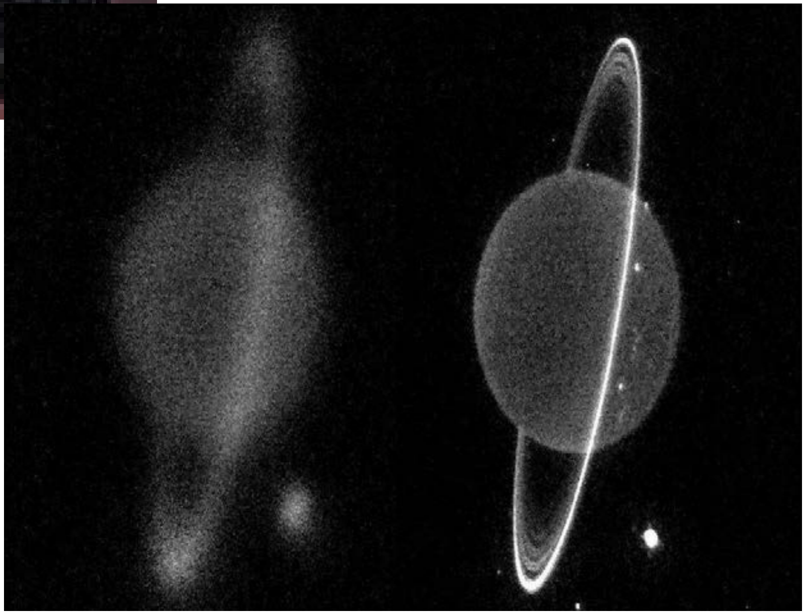
Galileo never had this:



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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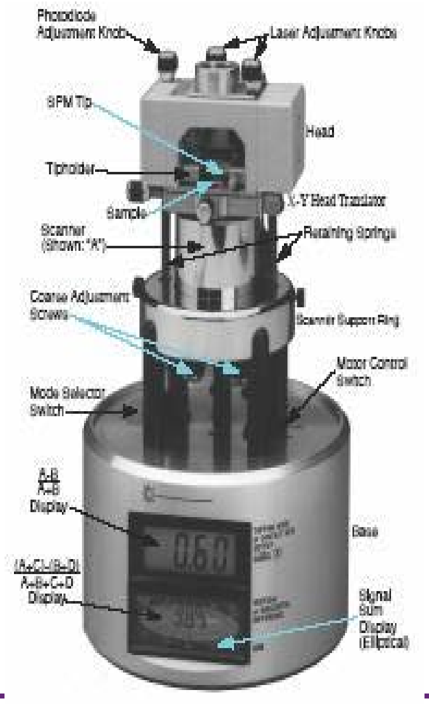
Neither did Pasteur have this:



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

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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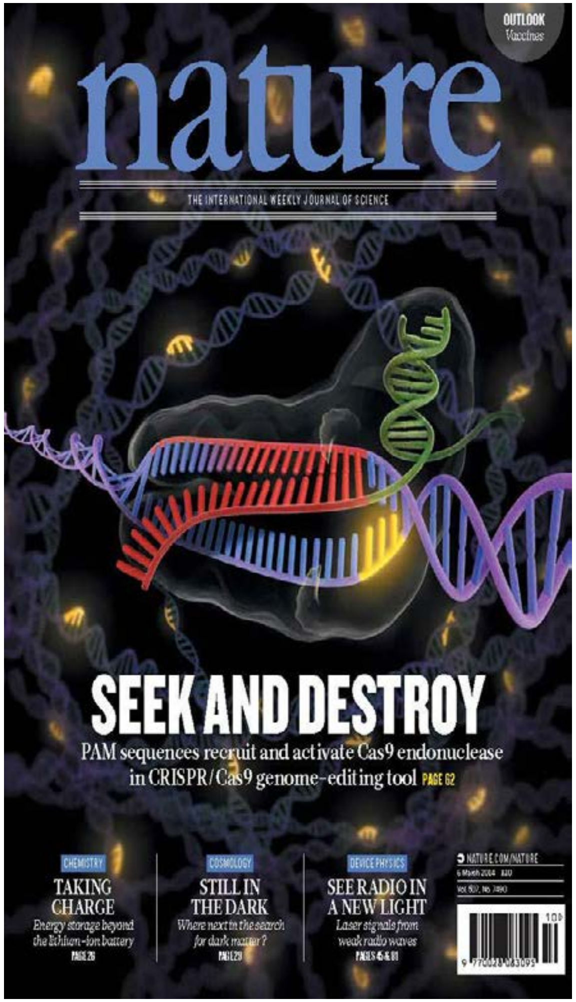
And Now: CRISPR

Jennifer Doudna



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The potential of CRISPR is immense:

From a recent essay in *Fusion*:

For obvious reasons, this notion of a mutant fish-tomato gives some people the willies, even though the vast majority of scientists say that it is perfectly safe. But Crispr, which allows scientists to cut and paste gene sequences more easily than ever, means scientists can more easily alter crops without adding genes from another species. To prevent those white button mushrooms from browning, for example, scientists just had to knock out the bit of DNA responsible for making them turn brown when you cut them. No Frankenfishmushroom here…

In academic labs, many other crops have already been engineered with Crispr, including soybeans, rice, and potatoes. The agricultural technology firm Dupont is testing using Crispr to make drought-resistant corn. It told the MIT Technology Review that it plans to start selling Crispr-engineered seeds by the end of this decade.

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And then there is this:

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Among the many advantages of lasers as a research tool are its monochromaticity, high optical coherence, high precision of high-powered energy, linewidth purity, and the ability to produce extremely brief pulses of light - as short as picoseconds or femtoseconds. Such pulses can be used to initiate and analyze chemical reactions.

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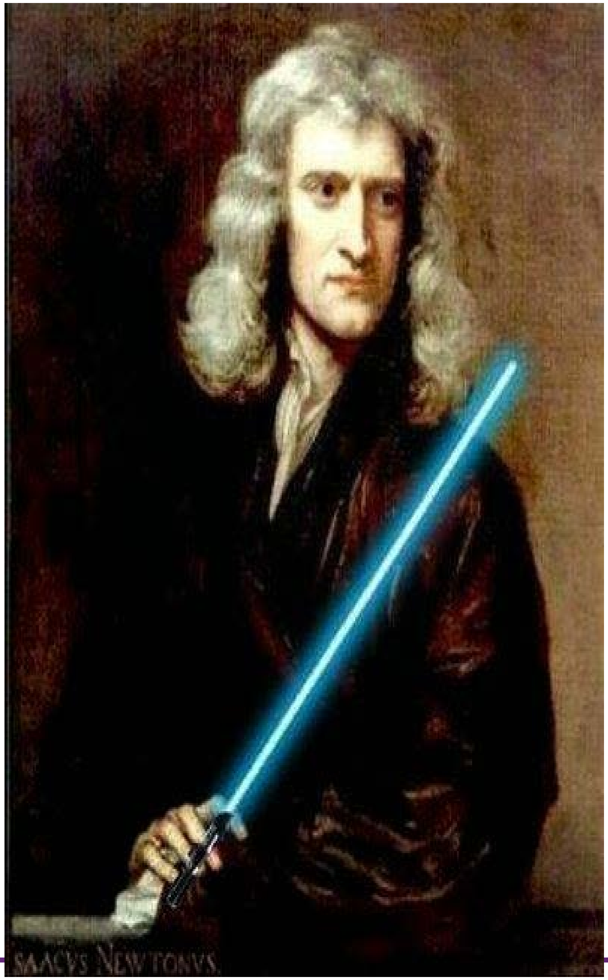
Wouldn’t Isaac Newton have loved to use a laser!

Well --- maybe he did?



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The uses of lasers

According to one unverified source, its inventor Theodore Maiman said in 1960 that it was a “solution in search of a problem.”

Today its uses in medicine, barcode readers, entertainment, and a thousand other applications in the economy (and may well have reached a saturation point, though we cannot be sure about that).

Yet it has also evolved into one of the most powerful tools science has its disposal. As such it will a much more important feedback effect: to stimulate and enable the emergence of completely unrelated techniques.

Today it is indispensable in scores of areas of research, among them:

A few examples of the power of this tool in research

- Laser-induced breakdown spectroscopy (LIBS)
- MALDI: Matrix-assisted laser desorption/ionization (used in mass spectrometry in for instance analytical protein chemistry)
- Particularly useful in biochemistry (e.g. photochemistry) and very high level magnification microscopes..
- Laser ablation (used to study e.g. the neural system by removing specific cells).
- Laser based *lidar* (LIght raDAR) technology has application in geology, seismology, remote sensing, and atmospheric physics.
- Laser annealing (in material science, esp. metals).
- Laser interferometers used in trying to detect gravitational waves, one of the holy grails of modern physics.
- And, the holiest grail of all: research in nuclear fusion. So far, no breakthrough.

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?

Every field of human inquiry, from molecular genetics and astrophysical dynamics to economic history and French medieval poetry relies on computers.

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. This (and for many other reasons) is why **quantum computing** is so promising. It can do this kind of calculations much faster than traditional binary-code based computers.

Perhaps just as promising: material science research

- 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 and Bessemer's invention of his cheap steel process in the same year in (1856)].*

- Scientists can now 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.]*

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. In 1700 Britain faced a number of well-defined technological problems:

1. How to pump water out of coalmines and prevent explosions.
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."

In 1815, these problems had been solved.

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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 the Haber-Bosch nitrogen fixing technique to the Salk-Sabin polio vaccines to Project Manhattan.

Gordon claims that these breakthroughs were “easy” and “low-hanging fruits” --- but at the time they were not. Maybe in 2200 the technique of nuclear fusion will seem “easy”.

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 fresh water scarcity.
4. Energy: fusion? Also: energy storage and transmission.
5. Multidrug resistance to antibiotics.
6. Digitally-driven mass-customization (and the materials needed)
7. Fish and seafood depletion.
8. Growing obesity.
9. Mental disease and 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 stagnation and 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.

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That said, there is no place for unbridled optimism

As Freud said with masterly understatement in his *The Future of an Illusion*, “While mankind has made continual advances in its control over nature and may be expected to make still greater ones, it is not possible to establish with certainty that a similar advance has been made in the management of human affairs.”

IMF has warned that the biggest threat to the world economy is “political risk”: rising protectionism, neo-nationalism, know-nothingism, obscurantism, and technophobia.

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The most serious “headwind” is NOT the national debt or the aging of the population as Gordon contends.

It is this:

‘Against stupidity, the gods themselves contend in vain.’ (Friedrich Schiller)

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Thank you

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