Supply Stocktake (2/10)

Note title: **Supply side secular stagnation and the future of innovation**

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Main message: A key current debate is whether or not slow growth in the advanced economies reflects some kind of secular stagnation. In the debate among technology pessimists and technology optimists, four main themes can be identified: these are the scale, duration and source of innovation, and the effects of demographic changes on innovation (Table 1). There are a number of emerging technologies that have the potential to improve productivity in a number of sectors. Neither technology optimists nor sceptics can predict the future, but the evidence presented in this note paints a more optimistic picture of the prospects for technological innovation compared to that contained in some of the academic literature.

Table 1: Summary of different views in the technological prospects debate

Theme	Pessimists	Optimists
Scale of existing innovations	No more great innovations like electrification or steam (Cowen, 2011, Gordon, 2012)	ICT is more important than electricity (Craft, 2004)
Impact of existing innovations	ICT revolution has run its course (Gordon, 2012)	ICT revolution has still long to go (Brynjolfsson and McAfee, 2011, Syverson 2013, Byrne et al, 2013)
Source of new innovations	No major innovations at the horizon (Cowen, 2011, Gordon, 2012)	Scientific discovery has changed and is self-perpetuating (Mokyr, 2014a,b)
Demographics	Lower population growth means less ideas are created (Gordon, 2014)	Ideas can circulate much faster thanks to new technologies (Jones and Romer, 2010)

1. Introduction

The impact of the Great Recession that began in 2008 has proved long lasting both in the U.S. and Europe and a key current debate is whether or not slow growth reflects some kind of secular stagnation. The difficult short-run environment has led to pessimistic assessments of the long-run growth prospects for the global economy: the February *Inflation Report* forecast round assumed an average annual growth rate of 2¾% for PPP-weighted world GDP in 2015-2018 versus 3½% in the two decades to 2007.

Slow growth could be part of a longer term trend of weaker supply-side growth. Fernald (2014) estimates that trend US productivity had started slowing well before the financial crisis, when the effect of the 1990s ICT boom started to vanish. This is supported by other evidence: Antolin-Diaz *et al.* (2014), for example, document a significant decline in long-run GDP growth in the United States, the bulk of which occurred prior to the Great Recession.

In this context, it is important to clarify the 'secular stagnation' concept. Dating back to the late 1930s, the term was recently revamped by Lawrence Summers in his 2013 IMF address[1] and echoed in several press articles[2] before the concepts and debate was finally expanded in a series of articles in recent VoxEu e-book.[3]

[1] IMF 14th Annual Research Conference In Honor Of Stanley Fisher, International Monetary Fund, November 8, 2013
[2] See for example the two articles in 'The Economist' on 19 and 22 November 2014:
http://www.economist.com/blogs/graphicdetail/2014/11/secular-stagnation-graphics
http://www.economist.com/news/finance-and-economics/21633860-demography-may-explain-secular-stagnation-no-country-young-people

The articles by Teuling and Baldwin (2014) and Eichengreen (2014) in that book offer three possible definitions of secular stagnation.

The first definition, which this note focuses on, postulates that current growth is low because the long-run potential growth rate has fallen. Bob Gordon's pessimistic view on the future US long run growth prospects (2012, 2014) refers to this hypothesis: he suggests that the gap of actual GDP to its potential is currently quite narrow and that the slow growth we observe is more a problem of slow potential growth than of weak demand.

A first possible definition for slow economic growth is that all the great inventions have been made and innovation is slowing.[4] Gordon (2012) argues that electricity, the internal combustion engine and indoor plumbing were more important for boosting productivity than any recent innovation, and that there is no great invention on the horizon that could revive anaemic growth. In his more recent article, Gordon (2014) points out that one does not need to assume low innovation to explain low GDP growth, and describes four other headwinds for the US economy (see box on the Gordon headwinds).

The second definition in the debate emphasises that the economy's supply-side potential *level* of GDP rather than the long-run *growth rate* has been permanently reduced by the Great Recession and the slow recovery that followed. This is consistent with the failure of output growth to recover to the pre-Great Recession trend and instead moving in parallel with this trend at persistently lower levels. In the US, this part of the secular stagnation discussion draws on an older literature on labour market hysteresis: persistent high unemployment can permanently impair the productive potential of the labour force through a reduction in labour force participation (*quantity* effect) as well as forgone on-the-job training and the atrophy of skills (*quality* effect). In the UK post crisis experience, however, a different type of persistent effect might be in place. The loss of productive potential could be linked to a stronger impairment of the financial system in the aftermath of the crisis. Another mechanism which could account for a permanent loss of potential supply is the loss of productivity due to the lack of implemented innovation, possibly because of uncertainty regarding the demand of new products in a recession: Bank analysis has shown that this is a significant albeit small factor for the UK.[5]

The third definition of the secular stagnation debate focuses on the deviation of actual growth from its potential. This definition is firmly Keynesian and postulates that the problem is one of stagnant aggregate demand, that is, households are not spending enough and firms are not investing enough even at near-zero interest rates.

This paper focuses on secular stagnation argument in terms of the 'supply side' and in particular, the prospects for technological innovation, the main driver of potential output growth. The note was produced as part of SEAD's long run growth programme, which aims to build a framework and toolkit for thinking about the drivers of economic growth and its prospects beyond the MPC's usual economic forecast horizon.

The note is organised as follows: section 2 delves into the debate on technological innovation, section 3 discusses the evidence and ideas behind the current technology trends and section 4 presents some tentative conclusions.

[3] 'Secular Stagnation: Facts, Causes and Cures', edited by Coen Teulings and Richard Baldwin, Centre for Economic Policy Research, 2014. Published as a *VoxEU.org* e-book.
[4] For a discussion on how innovation affects efficiency and therefore economic growth see .
[5] See the 2014 Q2 Quarterly Bulletin article "The UK productivity puzzle".

2. The prospects for technological innovation: pessimists vs optimists

Rapid technological progress, coupled with booming population growth, has been the force behind the strong and sustained economic growth in the last two centuries.[6] In particular, radical innovation[7] has often been associated with the introduction of a completely new and transforming technology – a so-called 'General Purpose Technology' (GPT), such as the steam engine, electrification and the ICT.[8]

Gordon (2012) links periods of accelerating economic growth to the timing of the three industrial revolutions, namely:

1) The first industrial revolution, which occurred between 1750 and 1830 and created the steam engine, cotton spinning, and railroads.
2) The second industrial revolution, which happened in the short interval between 1870 and 1900 with three central inventions of electricity, the internal combustion engine, and running water with indoor plumbing.
3) The third industrial ('digital') revolution, which began around 1960 with the invention of the personal computer and continued in the late 1990s with the creation of the internet and in the 2000s with the diffusion of mobile technology.

Will the current era – the digital revolution – be able to drive growth at the same pace as the previous two revolutions? In the debate among technology pessimists and technology optimists, four main themes can be identified: these are the scale, duration and source of innovation, and the effects of demographic changes on innovation. These themes are discussed in the rest of this section and summarised in Table 1.

a. The scale of existing innovations

Tyler Cowen (2011) in his recent book, *The Great Stagnation,* argues that the golden age of innovation is over, and the U.S. economy has entered a long period of stagnation as the great innovations have been already largely exploited. Similarly, Gordon (2012) argues the ICT revolution and the internet do not have the same power to drive growth as the technologies that occurred during the first and second industrial revolutions such as electricity and the internal combustion engine.

Other economists however see considerable reason for optimism about the potential for new and emerging technologies to keep productivity growth at a sustained rate. Craft's (2004) view, for example, is that the impact of ICT on labour productivity in the modern era has been greater than that of steam in the 19th century. The main reason is that the rate of decline of steam's relative price (due to faster technical progress in steam engines than in the rest of the economy) was quite modest for much of the nineteenth century, compared with the sharper decline in the ICT's relative price.

b. The impact of existing innovations

In Gordon's view, the ICT revolution has mostly run its course: the main impact of these innovations peaked in the late 1990s, with innovation since 2000 being centred on entertainment and communication devices that do not fundamentally change labour productivity.

Brynjolfsson and McAfee (2011) make the opposite argument, that the ICT revolution will take decades to fully play out. They argue that, instead of a 'Great Stagnation', the current environment is the start of a 'Great Restructuring': the computer, like all GPTs, requires parallel innovation in business models,

[6] for a review of the literature on the role of technological progress in economic growth.

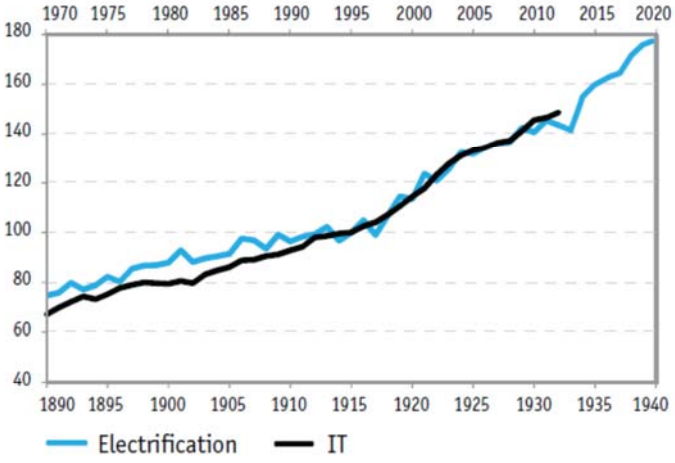
[7] *Radical innovations* are usually the result of a deliberate research and development activity. *Incremental innovations*, in the other hand, occur more or less continuously in any industry, although at a varying rate. They may occur as the outcome of improvements suggested by engineers and technicians directly engaged in the production process, or as a result of initiatives and proposals by end users (*user* innovation) rather than from formal R&D activities.

[8] For more detail on the economics of General Purpose Technologies .

organisational processes and institutions and skills. Innovation in these areas are required before full advantage can be taken of the ICT revolution.

According to Mokyr (2014a,b), there are two main reasons why economists are gloomy about the future of innovation. First, economists are trained to look at aggregate statistics like GDP per capita and total factor productivity: the contribution of ICT to people's wellbeing, however, is not evident from the productivity statistics because is it not captured in conventional measures of GDP. While these measures are suitable when pure quantities are concerned, they do not do well in measuring the products of the IT revolution. Many of these new goods and services are expensive to design, but once they have been invented, they can be replicated at almost zero costs. That means they tend to contribute little to measured output even if their impact on consumer welfare is very large.

Chart 1
Labour Productivity Growth During the Electrification Era (1890-1940) and the IT Era (1970-2012) in the United States
(1915 = 100 and 1995 = 100)



Source: Kendrick (1961); Byrne, Oliner, and Sichel (2013).

Source: Syverson (2013)

Syverson (2013) points out that labour productivity during electrification shared remarkably common patterns with the ICT era. During the electrification era, there was an initial period of around 25 years of relatively slow labour productivity growth, similarly to the initial phase of ICT from 1973-1995. Productivity growth then accelerated in both eras, spanning the decade 1915-1924 for electrification and the decade 1995-2004 for the ICT. Moreover, labour productivity growth slowed in 1924-1932, and similarly in the 2004-2012 slowdown (Chart 1). Thus history shows that productivity growth driven by GPTs can arrive in multiple waves, with slow labour productivity growth at the beginning of the diffusion of a GPT, followed by a decade-long acceleration, and then another protracted slowdown.

This argument helps explaining the productivity slowdown prior to 1995, when adaptation to the availability of computers and the internet first got underway, or the slow productivity growth now, when we are potentially on the eve of a second digital wave, in the form a robotics and human genome revolution. .

Finally, Byrne *et al.* (2013) present three types of evidence to the debate. First, they show that since 2004 IT has continued to make a significant contribution to U.S. labour productivity growth, though it is no longer providing the boost that it did during the productivity resurgence from 1995 to 2004. They also present evidence that semiconductor technology, a key ingredient of the IT revolution, has continued to advance at a rapid pace. Based on their projections of growth in trend labour productivity in the U.S., they see a reasonable prospect that the pace of labour productivity growth could rise back up to the long-run average and conclude that the IT revolution is far from over.

c. The source of future innovation (the role of scientific discovery or 'technology push')

Robert Gordon (2012) argues that no great invention equivalent to electricity or the internal combustion engine are on the horizon. For economic historians such as Mokyr (2014a,b), however, this argument is not consistent with the experience of the last 200 years. Pessimists have now been predicting slowing rates of invention and innovation for centuries and have been proven wrong. Mokyr postulates that the productive

potential of some emerging technologies (such as robotics and the human genome, for example) have only begun to be realised and that IT, biotech, and new materials are going to revolutionise the world.

The second reason for innovation pessimism is, according to Mokyr, a shortfall of imagination about the role of scientific advances. All industrial revolutions were preceded by rapid scientific advances.[9] The exact interaction between science and technology is complex, time-variant, and culture-specific, and, while technology can advance without a good scientific understanding of why techniques work the way they do, such progress would inevitably ran into diminishing returns and fizzle out.

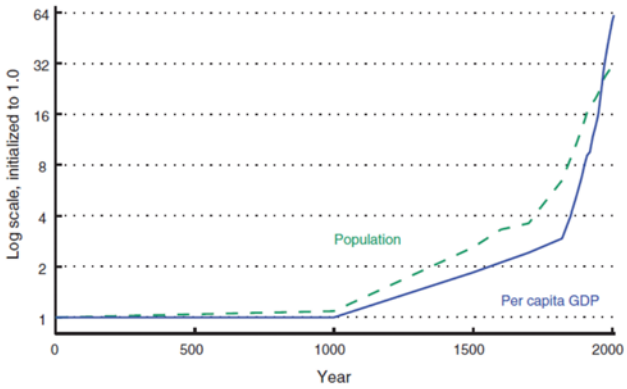
From the mid-19th century, scientific progress had led to unprecedented productivity growth and a sharp increase in economic welfare. The tools available today for scientific research are not only far more advanced than at any time in history: the digital codification of information has affected every aspect of science, completely transforming the research process, and causing the pace of innovation to accelerate. The digital technology is everywhere, from molecular genetics to nanoscience, and quantum computers promise to increase computational power by orders of magnitude. A striking example is the growing use of high-powered computers and radically new software in material science, where researchers can now can simulate the quantum equations that define the properties of materials, and experiment with materials having pre-specified properties. Another example is industrial 3D printing, which is transforming the R&D process by vastly increasing the capability to build prototypes.[10]

The interplay between science and technology creates a self-reinforcing process that is potentially unbounded. The *indirect* effects of science on productivity through the tools it provides to scientific research may, in the long run, prove to be an order of magnitude more important than the direct effects of ICT on output and productivity. The risk, in Mokyr's view, is not that the pace of innovation might slow, but that it could be so disruptive that its effects will be difficult to comprehend and assimilate.

d. Ideas, innovation and demographics

As Jones and Romer (2010) observe, demographic expansions lead to more ideas and, for most of human history, more ideas made it possible for the world to grow and support a larger population, in a feedback loop that generates accelerating growth rates.

Chart 2: Population and per capita GDP over the very long run.



Source: Jones and Romer (2010)

As Chart 2 shows, both population and per capita GDP were essentially flat for nearly 2000 years, and then rose very rapidly in the last two centuries.

As Gordon (2014) pointed out, the demographic landscape is unfavourable: world population will peak in this century and then decline. In Britain, the population will stop growing in the coming decades while in the US it will grow at barely a third of the 1% rate that prevailed from 2000 to 2013.

As well as a direct impact on growth in potential output, this future slowdown in the world population growth could potentially have a indirect impact on innovation by reducing the

[9] Torricelli's barometer, for example, showed the existence of atmospheric pressure, which spurred the development of the first steam engine.

[10] 3D printing allows creating complex objects using a computer-controlled 'printer' that deposits successive layers of material to form a metal, plastic or even organic object. This is production technology is called 'additive manufacturing'

flow of new ideas generated, leading to lower pace of technological progress.

Many forces, however, could offset these trends. For example, the growing number of people living in cities and improvements in trade and communication links could make it easier to share ideas with a large number of people; rising levels of human capital per head could make the individuals better at discovering and sharing ideas; and, as discussed in the previous paragraph, thanks to the new digital technologies, the efficiency of the research process is continually improving. For these reasons, while the growth in the stock of ideas might no longer be supported by population growth, expansion of the technological frontier might still be possible (Jones and Romer, 2010).

Box: the Gordon 'headwinds': demographics, education, inequality, debt

Interest in Gordon's 2012 paper largely revolved around his discussion of the rate of innovation and its role in explaining faltering economic growth. His more recent article (2014) emphasises the other drivers of slow future growth given that the rate of innovation will not in itself cause low growth. Instead, four structural headwinds will act as additional barriers to US economic growth, which – together – will detract from the 1891-2007 average US per capita[1] growth rate of 2%. These headwinds are demographics, education, inequality, and government debt:[2]

a. **Demographics**: By definition growth in output per capita equals growth hourly labour productivity times growth in hours per capita. The US population is stagnant and life expectancy is increasing rapidly. The slowdown in productivity growth that began in the US 40 years ago was partly offset by an increase in the labour-force participation, as females and baby-boomers entered the labour force. In contrast, during 2004 - 2014 the participation rate in the US has declined. According to Gordon, demographic trends account for over a 1pp reduction in the growth of per-capita US real GDP for any given growth rate of labour productivity.

b. **Education:** Throughout most of the 20th century, rising high school completion rates permanently changed the productive capacity of US workers boosting aggregate productivity, but according to Gordon, this trend was over by 1970, and now that the mass education revolution is complete, no further increase in the average US education level is to be expected.

c. **Inequality:** Income inequality continues to grow: the raising share of the top 10% of the income distribution has, according to Gordon, deprived the middle class of income growth since 1980. Because people at the top of the income distribution have a smaller marginal propensity to consume than households in the middle and low parts of the income distribution, current levels of consumption will become unsustainable.

d. **Public debt:** The fourth headwind is the predicted upward trend in the ratio of government debt to GDP: future tax revenue will grow more slowly, boosting the debt in the numerator of the debt/GDP ratio, while the denominator will grow more slowly, thus further increasing the ratio. The gloomy outlook for public debt makes current public services unsustainable and a fiscal correction will, according to Gordon, knock off 1.2% from US per capita growth.

1 Gordon focuses on GDP per capita growth given the interest in future standards of living and the distribution of income.
2 The first two are 'supply side'-type explanations, while the other two focus on the demand side.

3. Emerging technology trends and innovation prospects

Baily *et al.* (2013) argue that, thanks to a number of emerging technologies, there is tremendous scope to improve productivity not only in the manufacturing sector, but also in industries such as health care, infrastructure, education and government, which have lagged behind historically. They provide some examples of the type of opportunities available in different industrial sectors of the economy from some of the emerging technologies.[11]

Industrial robotics has the potential to fundamentally change ***manufacturing*** by increasing precision and productivity without incurring higher costs.[12] 3D printing[13] could generate a new ecosystem of smaller value chains and new companies providing printable designs on the web, making everyday products endlessly customizable. Big data and advanced analytics are particularly relevant to the manufacturing sector, which already owns large, fully digital data sets in several functions such as R&D and product development or supply chain optimization.[14] The so-called 'Internet of Things' offers the possibility to connect machines and equipment to each other and to common networks, allowing for manufacturing facilities to be fully monitored and operated remotely.

In ***health care and life sciences*****,** data driven decision-making, which allows the collection and analysis of large datasets, is already changing R&D, clinical care, forecasting and marketing.[15] Personalization and the 'quantified self' that enable the development of highly personalized treatments and medicines is a major trend in the use of big data in health care.

The ***infrastructure*** sector has been lagging behind with no measured gain in labour productivity in the last 20 years. Emerging technologies could enhance the existing infrastructure though, for example: the creation of Intelligent Transportation Systems (ITS) for roads, rail, airports, and ports, which could massively increase asset utilization; the introduction of smart grids, which could help save on power infrastructure costs and reduce the likelihood of costly outages; and efficient demand management, which could dramatically lower per-capita energy use**.**

The rest of this section discusses the technologies that are likely to be important, radical and pervasive over the next few decades, as identified by the McKinsey Global Institute (2013) and the UK Government Office for Science (2013).[16]

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[11] Although their analysis is based on the US economy, many of the examples can also apply to the UK.

[12] Baxter, for example, is a robot developed by Boston's Rethink Robotics with the capability to work safely alongside humans. Baxter's arms can sense a human in their path and stop movement.

[13] see footnote 10.

[14] In a report on the economic impact of Big Data by McKinsey Global Institute (MGI, 2011) the application of big data and advanced analytics to R&D and product development was estimated to reduce costs by 20-50 per cent and a big data-enabled supply chain optimization was estimated as yielding a 2-3 percentage point profit margin improvement.

[15] McKinsey Global Institute's 2011 report on Big Data estimated the long term potential of applications across health care to be over $300 billion per year, with more than $200 billion savings on national health care spending.

[16] There is significant overlap with this list and the current Government's investment in the 'eight great' technologies, identified by David Willets, which include: big data and energy-efficient computing; robotics and autonomous systems; life sciences, genomics and synthetic biology; regenerative medicine; agri-science; advanced materials and nano-technology; energy and its storage; satellites and commercial applications of space (BIS, 2014).

Table 2: Important and pervasive future technologies[1] and estimates of the potential economic impact (includes consumer surplus)

Technology	Description	Likely impact on production	MGI's estimated economic impact ($ trillion, annual)
Mobile internet	Increasingly inexpensive and capable mobile computing devices	Likely to become general purpose tools for production activities, also allowing for directed marketing, remote healthcare and personalisation of products	3.7-10.8
Automation of knowledge network / big data	Intelligent softare systems that can perform knowledge work tasks	Increased automation of many tasks and increased volume and detail of information caputured by businesses	5.2-6.7
Internet of things	Networks of low-cost sensors and actuators for data collection, monitoring, decision making, etc	Increased business optimisation, resource management, energy minimisation and remote healthcare	2.7-6.2
Cloud technology	Use of computer hardware and software resources delivered over a network or the internet	Increased ability to control multiple elements of the production process and increased opportunities to enhance productivity, supply chain management, resource and material planning, etc	1.7-6.2
Advanced robotics	Increasingly capable robots with enhanced senses, dexterity and intelligence to automate tasks	Likely to make many routine operations (including healthcare and surgery, food preparation) obsolete	1.7-4.5
Autonomous and near-autonomous vehicles	Vehicles that can navigate and operate with reduced or no human interaction	Boost the development of computer vision, sensors including rader and GPS and remote control algorithms	0.2-1.9
Next-generation genomics	Fast, low-cost gene sequencing, advanced big data analytics and synthetic biology	Impact on medicine, agriculture and production of biofuels and drug discovery	0.7-1.6
Energy storage	Devices or systems that store energy for later use, including batteries	Reduced cost of energy and its transport and the widening of reliable energy sources to developing countries	0.1-0.6
Additive manufacturing / 3D printing / advanced materials	Additive manufacturing techniques to create objects by printing layers of material based on digital models; materials designed to have superior characteristics or functionality	Greater flexibility in location of manufacturing, increased personalisation of products	0.4-1.1
Renewable energy	Electricity generation from renewable sources	Reduce resources used in production, including energy and water. Reduced climate impact	0.2-0.3

To compile this list, McKinsey Global Institute (MGI) uses various criteria to identify the 'technologies that matter', in other words, technologies that have the greatest potential to drive substantial economic impact and disruption by 2025. These criteria include technologies that:

a. are rapidly advancing (e.g. gene-sequencing technology)
b. have a broad reach (e.g. mobile internet)
c. have potential to create a massive economic impact (e.g. advanced robotics) and
d. have the potential to dramatically change the status quo (e.g. energy storage technology).

Economic impact and disruption is expected to come from falls in the prices of technologies and the subsequent increases in their use (e.g. mobile internet and advanced robotics) and/or improved efficiency (e.g. increase in the number of miles driven by autonomous or near-autonomous vehicles without accidents).

To estimate the economic impact of these emerging technologies, MGI (2013) captures the total value (including the consumer surplus) of each technology as companies commercialise them, by considering feasible scenarios for technology advancement, reach and resulting productivity or value gains that could be achieved by 2025. Their analysis assumes that any barriers to technology adoption and value creation can be overcome.

More detail on the impact of these technologies on different sectors in the UK is discussed in a note covering the Agent's fieldwork on innovation.[17]

4. Concluding remarks

Is there any evidence that innovation is faltering? While neither sceptics nor optimists about the prospects technology-driven growth can predict the future, and technologies and innovations are diffused and adopted at unpredictable rates, the evidence presented in this note paints a more optimistic picture of the prospects for technological innovation than that contained in some of the academic papers. Many economists agree that the digital revolution is as – if not more – important than the previous industrial revolutions and that it has still far to go in terms of impact on productivity.

The novel argument in the debate is Mokyr's decription of the accelerating features of the scientific process and the potentially exponential benefits of the digitalization of the R&D process.

The risk is not, as some economists postulate, that innovation has stopped. The limits to productivity growth might lay in the inability to exploit future opportunities by failing to invest in new technologies today, as well as in the new skills their adoption will require in the future.

The analysis of emerging technologies, described in the previous section, leads to several broad observations. First, new technologies can drive productivity and economic growth, but may also shift the global centre of gravity across sectors and regions. For example, advanced robotics could mean that the advanced economies could compete with developing countries as low-cost production locations, particularly on quality, delivery speed and customisation.

Second, the potential impact of technologies on developing economies, in general, may be more significant than that for developed countries: improved energy storage technology could make electric cars more competitive and hence increase their use in advanced economies, while this technology could facilitate access to electricity in developing countries, leading to a much higher impact.

Third, the impact of new technologies will also have a differential impact within countries: new sources of employment are likely for highly skilled workers, innovators and entrepreneurs, while low-skilled workers could be replaced with machines. Many believe this will lead to an increased income inequality: perhaps Gordon's concern in this area should be taken seriously.

Fourth, increased trade openness and domestic competition are likely to facilitate diffusion (OECD, 2012). The World Bank (2008) includes increased foreign direct investment and international migration to the list of drivers of technological diffusion to the emerging economies.

[17] 'Innovation – Intelligence from the Agency Network' by

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