Special theme

This year's special GII theme looks to the future of innovation-driven growth, and asks: Is stagnation here to stay, or are we about to enter a new era, where innovation waves reinvigorate economic growth and productivity globally?

What is the future of innovation-driven growth: Productivity stagnation or revival?

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The question of how innovation will affect our well-being over the coming decades has attracted the attention of scholars, policymakers and industry leaders.

Are we likely to live through a period of stagnation or will major innovations emerge that change all our lives for the better?

In the past, innovation has been the key driver of economic growth. Innovation has helped us to improve productivity – that is, how efficiently we produce things. An improvement in productivity directly boosts economic output relative to the population (gross domestic product, GDP, per capita), which in turn improves living standards.

Over recent decades there has been an unprecedented investment in innovation, both by the public and the private sectors. One would have expected this investment to have borne fruit in terms of higher living standards and improved well-being.

Yet, despite a massive growth in research and development (R&D) and other forms of innovation effort since the 1970s, recent technological developments are yet to generate the type of sustained productivity spurt seen in previous industrial revolutions. In fact, high-income economies are experiencing the opposite effect: rather than investment in innovation driving growth, there has instead been a prolonged slowdown in productivity since the 1970s. Often referred to as the “Great Stagnation,” this productivity growth slowdown brings into question the ability of innovation to create future growth.

At the same time, hope is on the horizon. Rapid advances in biomedicine, energy and information and communication technology (ICT) have the potential to significantly transform every aspect of the economy, leading some experts to predict that the world might, after all, be on the cusp of a new innovation-driven era of high productivity growth.

This 2022 edition of the *Global Innovation Index* (GII), with contributions by experts (available online), casts a spotlight on future productivity growth driven by innovation.[1] The key question addressed in this edition of the GII is which scenario is most likely to prevail – one of technology pessimism or one of optimism? Which technologies and what sectors will make a difference? And what roadblocks must be overcome before the route is clear toward a productivity revival?

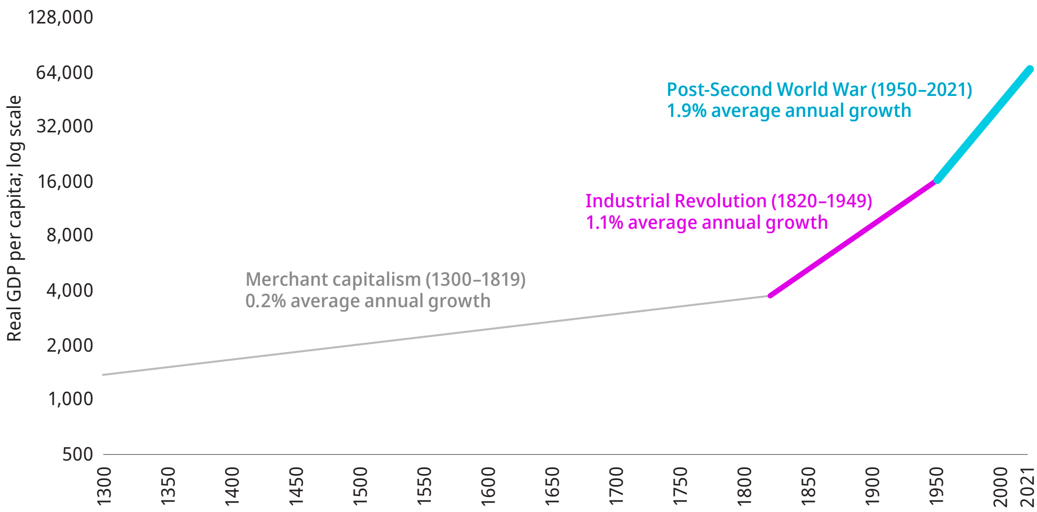
To answer these questions and more, this introduction to the GII 2022 Special theme first assesses the severity of the productivity growth slowdown since the 1970s that continues up to the present day. The main reasons for pessimism about the future of innovation-driven growth are laid out, but also the causes for optimism. We look at two upcoming innovation waves most likely to finally bring productivity stagnation to an end. Lastly, business and policy recommendations for overcoming the barriers to future innovation-driven growth are formulated.

How infrequent spurts in innovation-driven productivity – often with long delays between – started to boost living standards and bring massive changes

Major economic downturns aside, productivity and economic output grew year-on-year worldwide throughout the 19th and 20th centuries.

Historically speaking, this is a relatively recent phenomenon.[2] Effectively, before the 19th century, even those countries with the highest standards of living (measured in GDP per capita) did not experience any notable change in productivity and economic output for hundreds of years (Figure 13). It was only from the 1820s onwards that living standards started to rise significantly. From 1820 to 1949, the average annual per capita growth rate was 1.1 percent, after the Second World War from 1950 to 2021 rising to 1.9 percent.

Figure 13 Real GDP per capita levels at the frontier, 1300–2021



Source: Authors' own representation, updated from WIPO (2015).[3]

A major contributor to higher living standards is improved productivity, that is, the increasing amount of goods and services produced from given labor and machinery. Productivity growth has accelerated significantly since the 19th century. Whereas it took 50 years for productivity to double after 1870, productivity has since doubled roughly every 25 years. As a result, in 2021, an hour worked in the Group of Seven (G7) economies produced, on average, 24 times more goods and services in comparison to 1870.[4]

The increase in living standards since the 19th century and the First Industrial Revolution can be traced back to technological breakthroughs, new waves of invention and innovation, and the effective diffusion of new technologies across economies. These innovation waves disrupted entire industries and incumbent businesses, on average for the better.

However, such innovation-driven growth spurts cannot be taken for granted. Innovation waves – what experts sometimes call industrial revolutions – are rare, take decades to happen and require a myriad of complementary conditions to fall into place before they come about. They are marked by radical innovations, such as the steam engine, electricity, chemicals and mass production, having the effect of boosting productivity across all sectors.[5] They have also coincided with periods of severe recession and social transformation.[6]

Past and future productivity-driven growth spurts initiated by innovation waves have four essential ingredients.

1. A sustained effort to turn breakthrough inventions made at the technology frontier into innovations with the potential to succeed in the marketplace.

2. Scalable innovations readily diffused and adopted across a wide range of sectors in the economy, building on all required complementary innovations.[7]

3. Relatedly, emerging economies adopting innovations at the technology frontier, thereby driving up world productivity.[8] (This process of technological catch-up is not automatic.)

4. The confronting of headwinds likely to lower living standards, such as an aging population. Productivity growth needs to outrun countervailing forces for welfare to increase.

Ingredients 2 and 3 taken together mean that any global innovation-growth stimulus often only occurs after a long delay.[9] Invariably, innovation and productivity effects occur very slowly during the initial stages, only to be followed by a sharp takeoff and impact years later.[10]

These four ingredients are key to assessing any potential future productivity growth spurts.

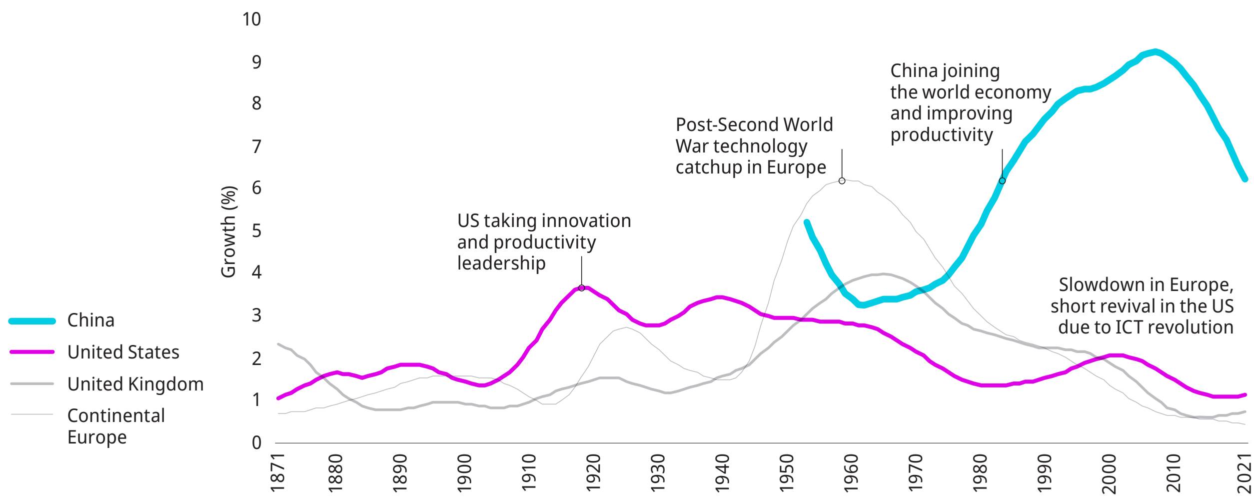
Productivity slump since the 1970s: Is the link between innovation and productivity broken?

Today, innovation-driven productivity growth seems to be broken. High-income economies, in particular, are struggling to replicate their success of the recent past.

Is the persistent productivity slowdown getting worse?

After the 1970s, a period of sustained slowdown in productivity growth began (Figure 14; see also GII 2022 Expert Contributions from van Ark and Fleming; Petropolous). Before then, productivity growth had been stimulated by the aforementioned innovation waves: the United States of America took the innovation and productivity lead in the 20th century, with the post-Second World War period especially fruitful, as technology diffused out from the more advanced United States to reach Europe and later Japan and the Republic of Korea.

Figure 14 Labor productivity growth, 1871–2021



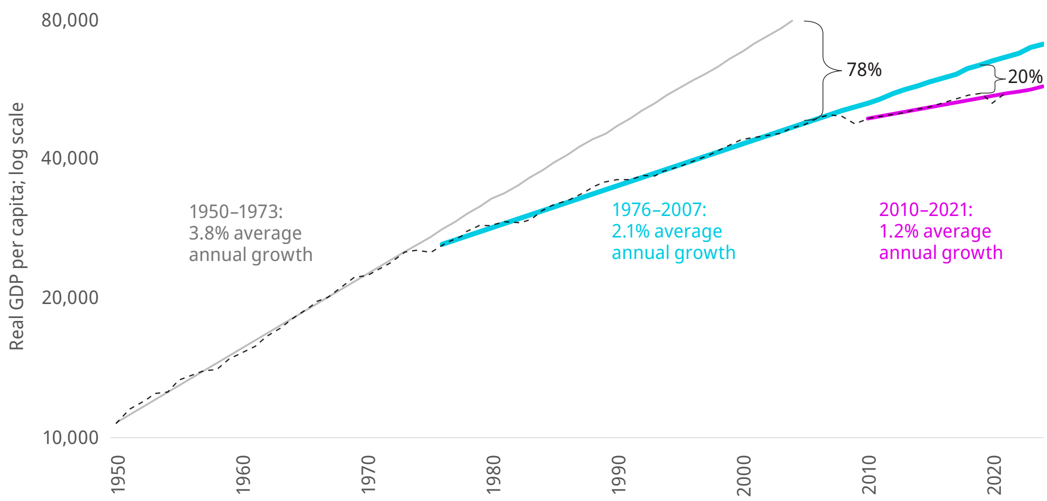
Sources: Authors' own representation based on 1870–1950 data from Bergeaud *et al*. (2016); 1950–2019 data taken from The Conference Board Total Economy Database™ (April 2022).

Note: Continental Europe refers to France, Germany and Italy.[11]

The first period of productivity slowdown occurred somewhere around the 1970s (see Figures 14, 15 and 16). The drop from a 3.8 percent average annual growth rate between 1950 and 1973 to 2.1 percent between 1976 and 2007 is visible almost across the board, with the sole exception of the Republic of Korea (see Figure 16). A further drop to a 1.2 percent average annual growth between 2010 and 2021 can be seen in almost every Organisation for Economic Co-operation and Development (OECD) country, this time including the Republic of Korea.

The United States experienced a brief uptick in growth during the 1990s and early 2000s, often associated with the ICT revolution (see Revival or stagnation?). However, this proved short-lived and Europe was not a beneficiary of this innovation wave. Furthermore, the productivity growth slowdown intensified again around the time of the 2008/2009 global financial crisis, and has worsened since.

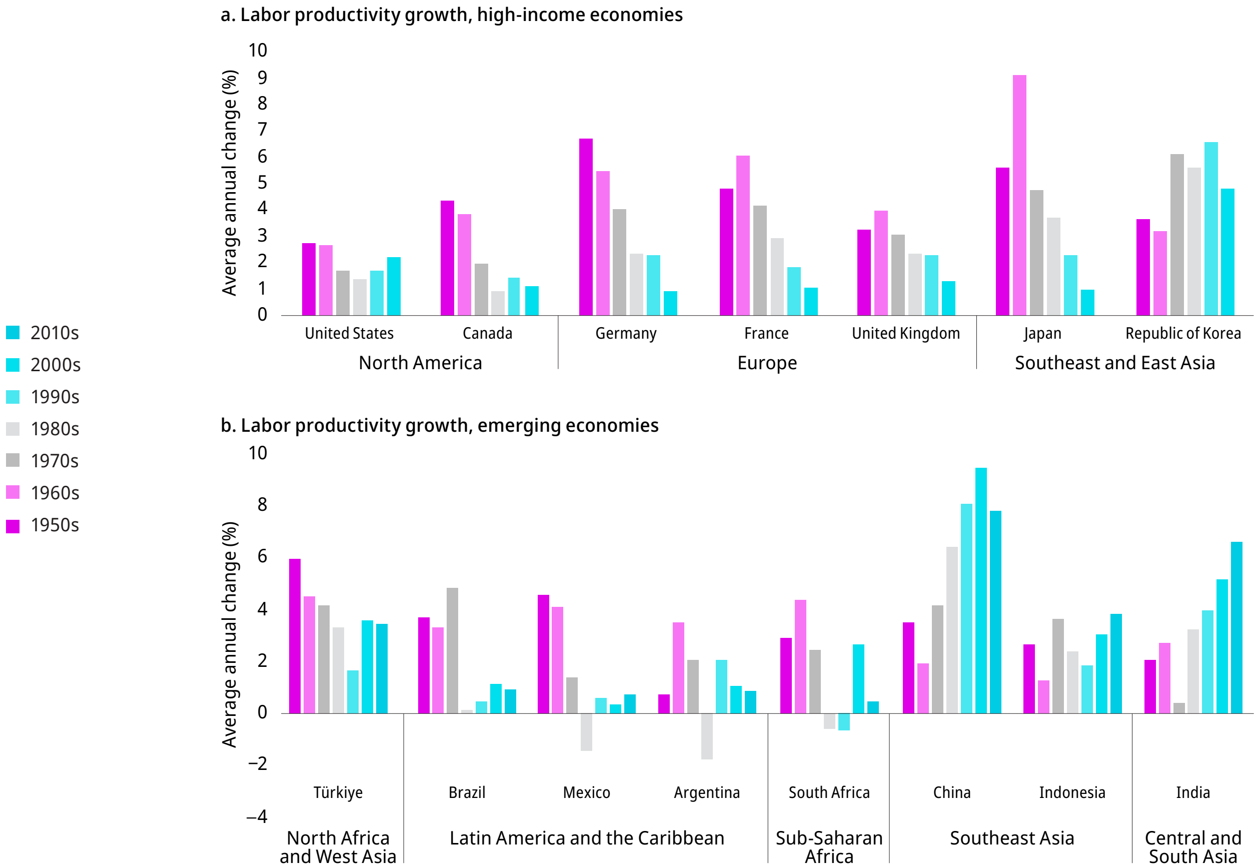
Figure 15 Slowdown in GDP per capita growth in OECD economies, 1950–2021



Source: Authors' own representation based on data from The Conference Board Total Economy Database™ (April 2022).
Note: Real GDP levels are expressed in 2021 International Dollars, converted using purchasing power parity (PPP).[12]

What does this slowdown mean in practice? The trend lines in Figure 15 show that living standards would have been significantly higher in the absence of a productivity growth slowdown. If the 1950–1973 real GDP per capita growth trend had continued until 2007, real GDP per capita would have been 78 percent higher that year. Furthermore, if the already slower trend from 1976–2007 had continued until 2021, real GDP per capita would nevertheless have risen by a fifth (20 percent) in no more than 14 years.

Figure 16 Slowdown in labor productivity growth, 1950s–2010s



Source: Authors' own representation based on data from The Conference Board Total Economy Database™ (April 2022).
Note: Labor productivity refers to GDP per hour worked.

Ironically, this productivity growth slump has coincided with soaring innovation investments, as measured by spending on education and R&D, the availability of venture capital (VC), the filing of intellectual property (IP) and investments in other forms of intangible assets.[13] Economists have accordingly suggested a marked decline in the productivity of R&D.[14]

These boom-and-bust figures apply only to high-income economies. For middle-income economies, the trend is more diverse – and fraught with measurement uncertainties. China's productivity growth began to gather speed from the 1980s onwards, once the country had started to integrate into the world economy, has slowed prematurely over the last decade (see Figures 14 and 16b).

The vast majority of other emerging economies were never part of the productivity spurt, in particular Africa and Latin America, but also the bulk of economies in the Middle East or Asia. Notable exceptions are India, Indonesia and Türkiye.

Techno-pessimist or techno-optimist?

Technology pessimists argue that the supply of innovation has diminished, compounding the other factors slowing improvement in living standards.

Techno-pessimist #1: Transformative ideas are getting harder to find

The central argument of techno-pessimists is that innovations are, on the one hand, becoming more difficult to find, and, on the other, that those that are emerging will not have the same transformative impact on productivity as did past technologies. On the first point, it is argued that the low-hanging fruit of innovation and technology has already been picked.[15] Despite massive innovation investments, it is becoming more costly to find and develop potentially novel innovation; the rate of scientific progress has slowed and the productivity of R&D has declined.[16] It is further argued that emerging novel technologies are less revolutionary than past breakthroughs.[17] The "great inventions" of the past – ranging from the combustion engine, electrification, plumbing, airplanes to barcodes[18] – allowed a dramatic shift from an agrarian to an industrialized economy, and subsequently led to the development of service-based economies, making today's innovations appear modest in comparison.[19]

Techno-pessimist #2: Innovation systems are no longer so productive

A second argument is that today's innovation systems, including the interplay between innovation actors churning out impactful inventions, are less effective than in the past. This argument runs contrary to the hypothesis that, today, public–private knowledge transfer works better, thanks to more efficient knowledge transfer policies and practices.[20] On paper, firms are spending more on R&D than ever before. However, it is argued that scientifically excellent in-house laboratories renowned for their innovations between the 1950s and 1970s – such as, for instance, the American Telephone and Telegraph Company (AT&T) or International Business Machines (IBM) – once key to the commercialization of breakthrough inventions, are now in rapid decline.[21] Large firms are increasingly choosing to license research from universities rather than carry out their own R&D. With diminished in-house research capacities, the link between innovation in the marketplace and scientific discoveries in the laboratory is weakened. In turn, this reduces the overall speed and effectiveness of innovation creation, adoption and impact.

Techno-pessimist #3: Other factors are making it harder for innovation to make a difference

Finally, the conditions for innovation making a lasting difference to growth have worsened. Even if innovation had the same potential as before – which it does not – several factors (dubbed headwinds)[22] will continue to drag on long-term growth. One of these factors is an aging population (see Will innovation beat the slowing growth in living standards?).

Not all experts agree with this bleak, "Great Stagnation" hypothesis. What then are the counterarguments? The core argument put forward by technology optimists is that innovations take time to unfold, due to the many challenges faced by innovation diffusion at every level, from the firm, sectoral and regional levels all the way up to the international level. In fact, they go further by arguing that we are on the cusp of a new innovation-driven productivity boom.

Techno-optimist #1: Historically speaking, we are doing fine; non-stop exponential productivity growth is the wrong benchmark

Compared to historic data, productivity growth rates over the past decades have remained above average (see Figure 13). Moreover, using rates seen prior to the 1970s as a benchmark for the future is arguably off the mark. This point of view is supported by a recent, influential paper arguing that productivity does not grow exponentially, but rather that the big growth spurts seen in the 19th and 20th centuries are the exceptions, not the norm.[23] Today's "additive" growth will still lead to vast improvements over time (see Figure 22, showing advanced economies to have roughly doubled their productivity since the 1970s slowdown began).

That does not mean experts exclude the possibility of a historically significant productivity growth push. Indeed, techno-optimists argue that big science has already begun producing major breakthroughs, whose transformative potential across all industry sectors (not only ICT) is on par with, or even superior to, previous innovation and productivity spurts (see Revival or stagnation?).[24] The rapid adoption and success of the messenger RNA vaccines in combating COVID-19 has probably played a large part in this renewed optimism. But techno-optimists also point to advances in other areas: for example, the rapidly declining cost of renewable energy (mainly related to wind, solar and geothermal (see the Global Innovation Tracker Dashboard on page 25 and GII 2022 Expert Contribution from Gutierrez de Piñeres Luna, Ocampo, Del Pilar Tapias, Morales, Otalvaro and Fernandez) and battery technologies (e.g., lithium-metal batteries), the rapid advancements in digital technologies (e.g., artificial intelligence (AI), nanotechnologies) and the sharply declining cost of space exploration (e.g., SpaceX).

Techno-optimist #2: It takes time for innovation to be absorbed and create impact

It takes a tremendously long time – sometimes decades – for new inventions and innovations to combine with other complementary processes and organizational innovations. The innovations that have occurred after the 1970s, particularly those during the 2000s, will eventually feed through to strong productivity growth. Artificial intelligence, quantum computing or advances in new materials or bioinformatics – none of which is inferior to past big inventions – will inevitably translate into higher productivity growth. This future is not yet here, but it is just around the corner.

Furthermore, the argument goes, the potential diffusion of existing technologies is massive. Untapped productivity gains are within grasp, but diffusion is imperfect at the firm, sector, regional and international levels.

Starting at the firm level, evidence shows technology adoption still concentrated within a few firms only – the super-firms (see Revival or stagnation?). The co-existence of productivity leaders alongside productivity laggards creates persistent productivity differences, slowing the process of creative destruction. Laggards lack the skills and resources to make the necessary investments in order to become as productive as those economies who lead in terms of technological sophistication and are thus able to push forward the productivity and innovation frontier (see GII 2022 Expert Contribution from van Ark and Fleming).

Moving to the next level, some sectors – the super-sectors – have experienced above-average productivity growth, including ICT, wholesale and retail, manufacturing, finance, but also agriculture. Despite this, the majority of sectors have performed below the overall economy average, or even seen a decline; namely, utilities, transport, education, entertainment, restaurants, construction and others (Table 10). A focus on this group of sectors will yield large productivity gains.[25] And, in middle- and low-income economies, the untapped potential is even greater. Only a few sectors, notably agriculture, have experienced productivity increases (see GII 2022 Expert Contribution from Braga de Andrade, Cosentino and Sagazio).[26] Large parts of developing countries' economies are informal in nature. Although such parts are measured, and consequently do not drag down observed productivity, it is nevertheless correct to say that productivity is typically low in informal sectors (see see GII 2022 Expert Contribution from Dosso).[27]

At the regional level, vast variations exist in the diffusion of productivity-enhancing innovations across regions, including in the European Union and the United States, as well as in emerging economies such as China, Colombia and Türkiye. Some regions – the super-regions – perform extremely well, while others, lacking agglomeration effects and locked in a low skills-wage-productivity trap, perform poorly (Figure 17).[28]

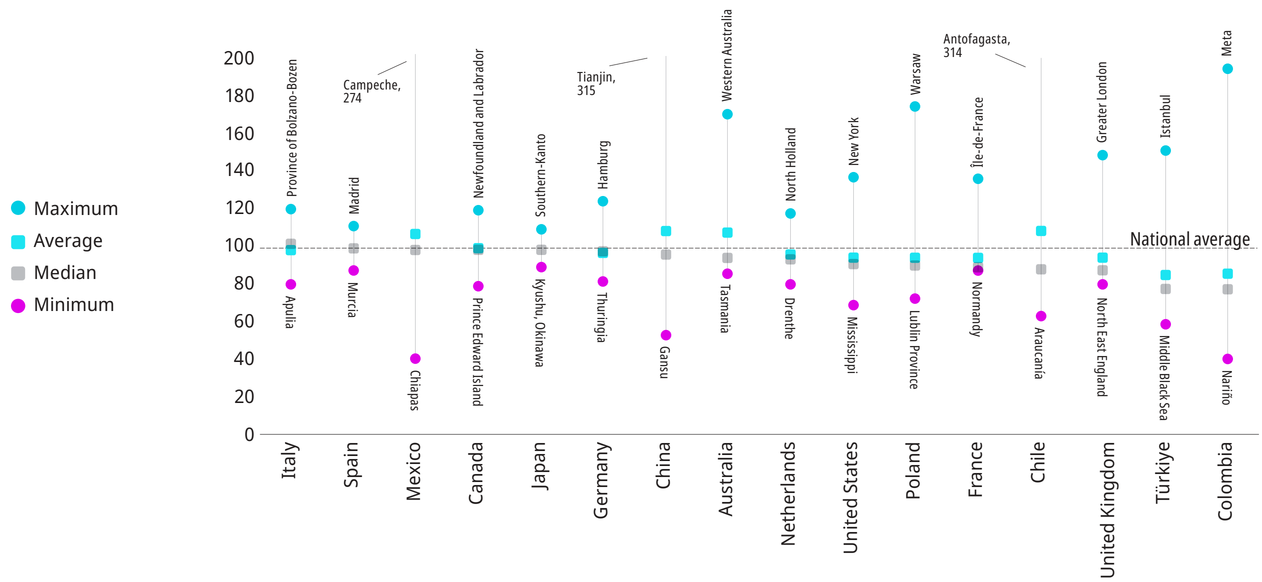
Table 10 Average productivity growth by sectors, 1996–2019 (average annual percentage change)

			United States %	Canada %	United Kingdom %	Germany %	France %	Japan %	Italy %	Unweighted G7 average %	Share in GDP %
Leading	Information and communication	J	5.4	2.0	8.9	3.8	3.1	2.1	2.1	3.9	5
	Agriculture	A	4.5	3.7	4.4	3.7	3.4	2.3	1.5	3.3	2
	Manufacturing	C	3.4	1.7	3.8	2.2	2.8	2.7	1.2	2.5	16
	Wholesale and retail	G	2.6	2.6	0.6	2.2	1.2	1.1	1.5	1.7	11
	Finance and insurance	K	2.1	2.5	1.9	−0.3	2.1	1.3	1.4	1.6	6
	Government	O	0.1	1.1	1.6	1.5	1.3	1.0	1.2	1.1	8
Economy-wide	Overall	A–T	1.5	1.2	1.2	1.2	1.1	1.1	0.3	1.1	100
Lagging	Transport and storage	H	0.4	1.0	0.7	1.6	1.4	−0.1	0.7	0.8	4
	Real estate activities	L	1.2	1.4	−1.3	1.5	1.2	0.2	−0.8	0.5	11
	Arts, entertainment and other services	R–T	0.1	1.2	−0.2	−0.2	0.9	0.1	−0.2	0.2	5
	Utilities	D–E	0.6	1.0	0.0	1.9	0.0	−1.0	−2.0	0.1	2
	Mining	B	2.2	−0.3	−4.4	1.8	−0.5	−1.2	2.6	0.0	1
	Professional, scientific, technical, administrative and support services	M–N	1.2	0.9	0.4	−1.2	−0.2	0.8	−1.8	0.0	10
	Health and social care	Q	0.7	−0.2	−0.2	0.7	0.2	−0.9	−0.8	−0.1	7
	Restaurants and hotels	I	0.4	0.6	−0.1	−0.3	−0.2	−0.9	−0.6	−0.2	3
	Education	P	0.2	0.5	−1.3	−1.2	−0.4	0.4	−0.4	−0.3	4
	Construction	F	−1.2	0.5	0.2	0.2	−0.6	−0.2	−1.1	−0.3	5

Source: Authors' calculations using data from national statistical offices and EU-KLEMS.

Notes: G7 refers to an unweighted average of the seven countries; share in GDP is likewise an unweighted average of GDP shares over the period 1996–2019; codes in the second column refer to the International Standard Industrial Classification of All Economic Activities, Rev.4.

Figure 17 Regional labor productivity differentials, 2020 or earlier



Source: Authors' own calculations using the OECD Regional Economy dataset.
Notes: Labor productivity refers to GDP per worker. The regions at the top of the graph are more productive than the average or median; those at the bottom are the least productive regions.[29]

Finally, vast untapped technology diffusion and productivity catch-up potential exists at the international level. While the productivity of most advanced economies has roughly doubled since the 1970s slowdown began, others have yet to catch up (see Figures 22 and 23).

Techno-optimist #3: Productivity might be under-measured or completely the wrong metric

The third and last techno-optimist argument is that productivity may actually be on the rise, but its full extent not captured by productivity statistics. GDP statistics were largely conceived during the Second World War.[30] At that time, a large portion of the economy centered around making goods, whereas, today, services activities predominate.

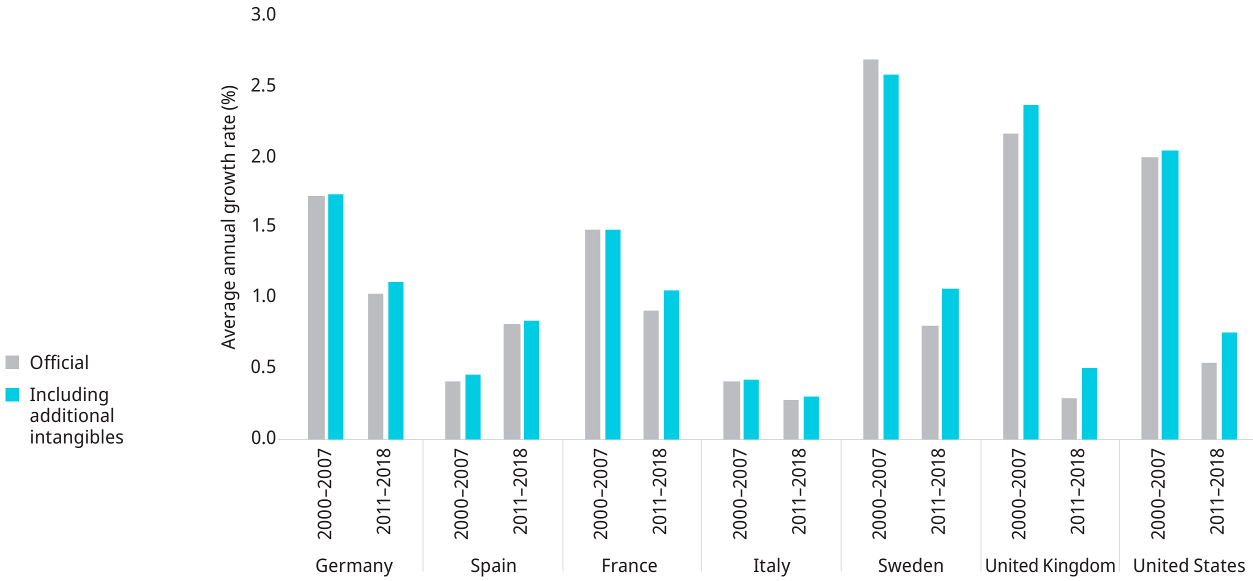
Conventions regarding the estimation of GDP (and national accounts more broadly) are updated every two decades or so to reflect a changing economy. Nevertheless, several measurement problems stand out. They are:

- how to better measure the services-oriented economy;
- how to account for the monetary benefits of notionally free digital services, such as online maps;

- the imperfect way intangible asset investments are accounted for;[31] and
- the imperfect way quality improvements are captured, first and foremost in ICT products, but also in other fields (e.g., car safety, health and so on – see Will there be an innovation-driven productivity revival?).[32]

Indeed, a better capturing of intangible asset investments – particularly in the field of economic competencies – leads to an increase in official labor productivity measures (Figure 18). National accounts similarly need to include the contribution made by substantial quality improvements in many different fields, including in health and education.

Figure 18 Labor productivity growth rate, selected countries, 2000–2007 and 2011–2018



Source: Authors' calculations using EU-KLEMS available at Luiss: https://euklems-intanprod-llee.luiss.it.

Others argue that productivity data is not just mis-measured, but entirely inappropriate as a measure of technological progress.[33] According to Nakamura (2020) "we are simply not 'seeing' innovation-driven productivity growth since the changes are too fast for our statistical systems to keep up with."[34] Moreover, productivity and GDP may no longer be adequate measures for capturing living standards or welfare either (see Will there be an innovation-driven productivity revival?). Environmental degradation is a significant externality that GDP as a measure fails to reflect.[35]

Importantly, this raises the possibility that the drivers of innovation might also have radically changed. Productivity used to be a paramount concern; nowadays, climate change issues, and more generally "value-based production," are key to pushing innovation. This being the case, the linkage between innovation and productivity gains will inevitably become weaker.

Revival or stagnation?

What follows assesses the likelihood of an innovation revival bringing productivity growth stagnation to an end.

Productivity figures getting better after a COVID-19 boost? Not really...

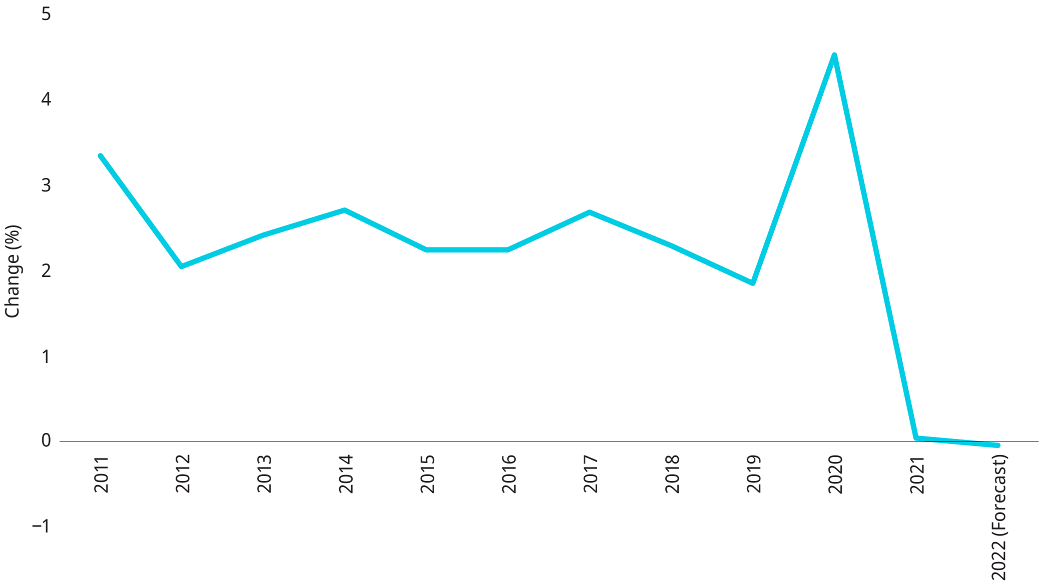
A pressing question is whether current productivity figures have experienced an uptick during, and possibly as a result of, the COVID-19 pandemic.

Indeed, 2020 and early 2021 data and related business executive surveys have nurtured this belief.[36] The crisis has supposedly accelerated technology adoption and diffusion, in particular as regards digitalization and novel forms of (remote) working.

Recent data shows 2020 to have seen the fastest rate of global labor productivity growth since the 1970s in such countries as Brazil, Türkiye, the United Kingdom, the United States and South Africa (in order of growth).[37] Global productivity figures spiked that year at 4.5 percent, up from 1.4 percent in 2019 (Figure 19; see also Global Innovation Tracker, this volume).

Yet, attributing this spike to a productivity revival would be wrong. First, it is the result of simple arithmetic: 2020 global GDP dropped by 3.3 percent, but total hours worked declined by more, 7.5 percent, thus boosting productivity. Second, lockdowns disproportionately impacted low productivity economic activities (e.g., in-person services), thereby boosting productivity through compositional effects.

Figure 19 Global GDP per hour worked, 2011–2022



Source: The Conference Board Total Economy Database™, April 2022.
Notes: Underlying levels of real GDP are expressed in 2021 international dollars, converted using purchasing power parity (PPP).

After 2020, global labor productivity fell sharply to zero in 2021, and is forecast to stagnate again in 2022, including due to the impacts of higher input costs for energy, as well as the supply chain disruption caused by the the Russian Federation–Ukraine conflict.[38] In most economies, productivity levels are likely remain below trend into the foreseeable future. As argued later, this does not mean that the accelerated digitalization prompted by the pandemic did not have a productivity effect. It probably did – it will just take time before it appears in the data.

Will there be an innovation-driven productivity revival?

Thankfully, the sharp declines in productivity for 2021 – and static forecast for 2022 – are driven down mainly by short-term factors, namely, escalating input costs and the shutting down and subsequent reopening of the economy that impacted low-productivity service activities in particular.[39] Therefore, the impact of innovation breakthroughs is not directly factored into these estimates.

So, what is the innovation-driven productivity revival outlook likely to be?

Digital Age and Deep Science: Two innovation waves in the making

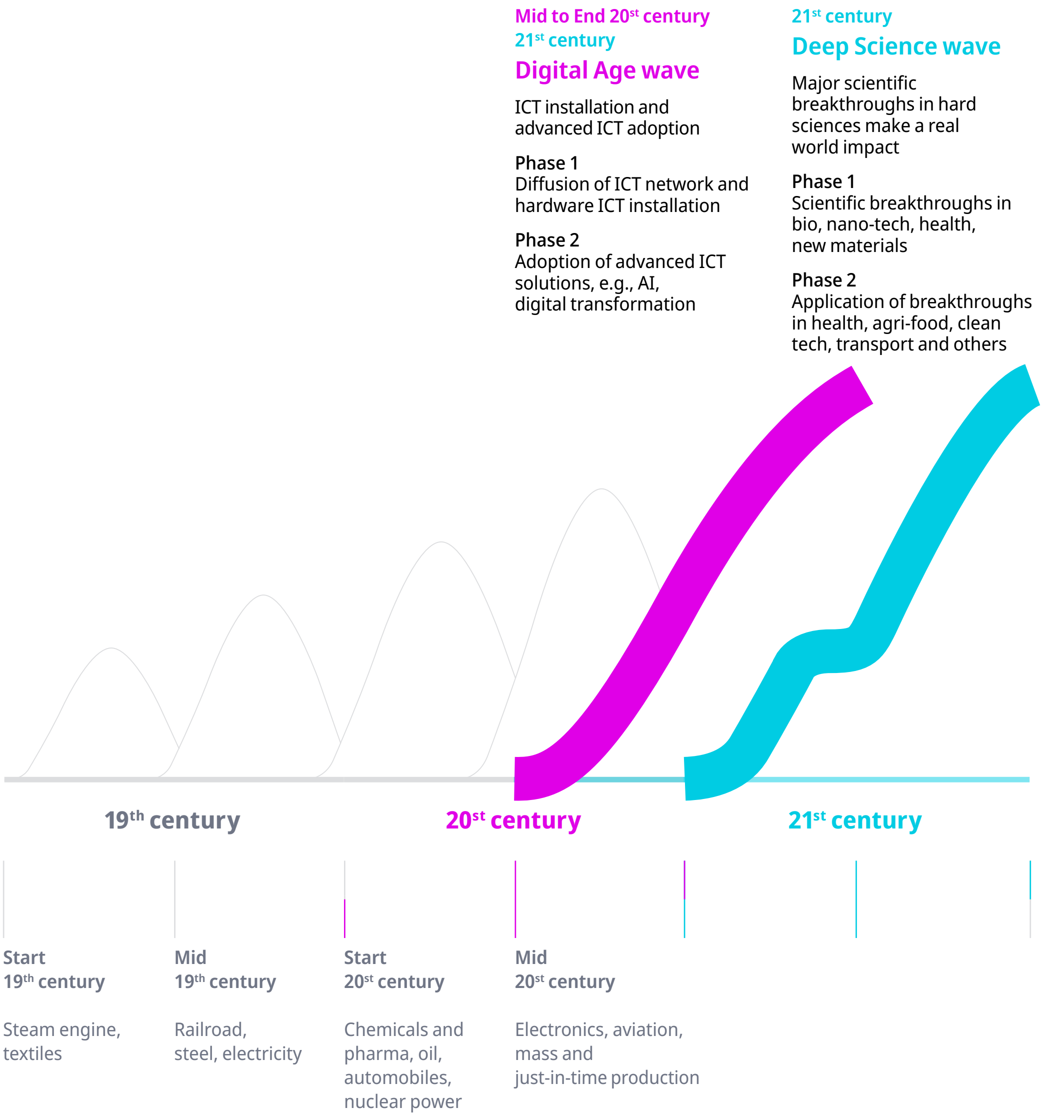
Evidence is building for two types of novel innovation waves emerging, each with the potential for large, measured – and possibly unmeasured – productivity and welfare impacts.

Digital Age wave: ICT surge in two parts

First, the ICT wave – which started in the 1970s and supposedly subsided in the late 1990s – is forecast to regain strength over the coming months and years (see GII 2022 Expert Contributions from van Ark and Fleming; Peters and Trunschke; Petropoulos).

This is best conceptualized as two consecutive ICT surges forming what we choose to call the "Digital Age wave" (Figure 20).

Figure 20 Past and future innovation waves from the 19th through the 21st century



Source: Authors' conceptualization based on references sources.[40]

The first ICT surge led to the installation of sophisticated communication networks and equipment – the internet, mobile devices and so on. This installation phase is not yet over, instead it continues to boom (Figure 21). While the ICT revolution led to an initial uptick in productivity growth in the United States, this neither lasted nor spread to other countries.

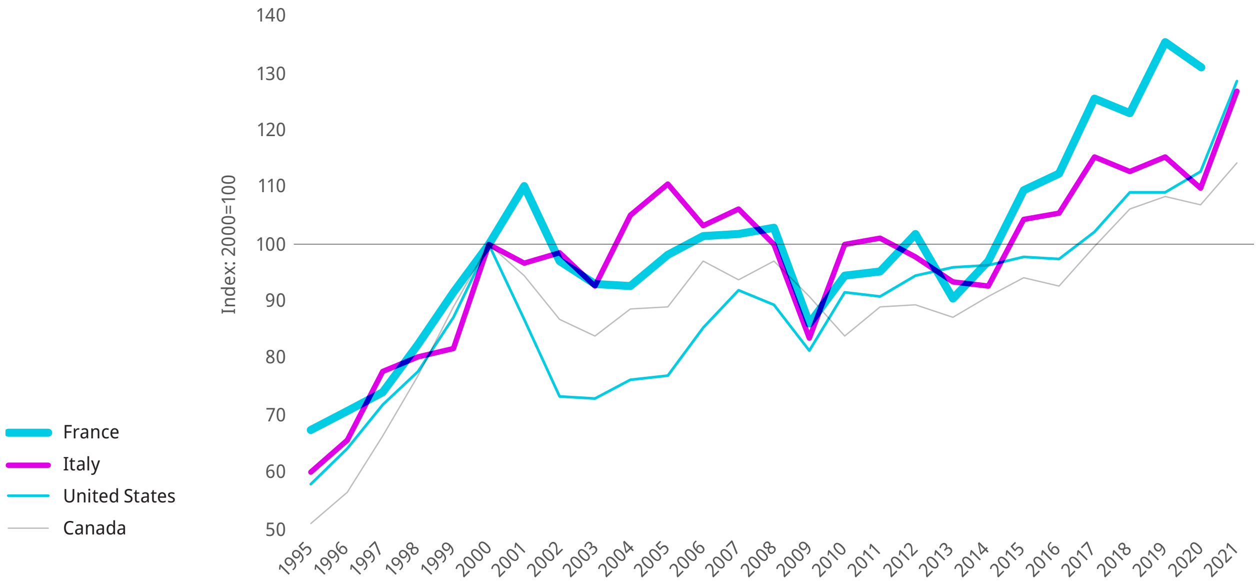
In a second surge, ICTs are diffusing as general-purpose digital technologies in the form of supercomputing, cloud computing, the internet of things (IoT), AI and automation (fueling the "New Digital Economy," as discussed in GII 2022 Expert Contribution from van Ark and Fleming).

In this Digital Age wave, the impact of ICTs unfolds in two ways:

- ***ICT as a research tool***: ICTs have had a powerful effect on scientific advances and R&D in fields such as bio-informatics, pharma, green tech and other scientific fields, leading many to observe a convergence of ICT, bio- and nanotechnology, and cognitive science research. As characterized by Cockburn and colleagues, ICTs are a general-purpose "method of invention" – with data analysis and simulation opportunities – profoundly reshaping the innovation process and the organization of R&D.[41]
- ***Advanced ICTs as a general-purpose technology***: The second ICT revolution will profoundly impact the organization of non-ICT sectors, in particular through the application of automation and AI, large-scale factor digitalization, 3D-printing and advanced robotics (see in GII 2022 Expert Contribution from Petropoulos, WIPO, 2019). If the adoption of these technologies follows suit, this would be a productivity game-changer in every manufacturing sector and also agriculture (see GII 2022 Expert Contribution from Braga de Andrade, Cosentino

and Sagazio), but – importantly – also in those large service sectors trailing in productivity, including education, health, transport and utilities, and for which existing ICT, robotics and other technologies are not yet fully ripe.

Figure 21 Investment in ICT equipment, 1995–2021



Source: Authors' calculations using national sources and Eurostat.
Note: Nominal investment in ICT equipment (hardware and communication equipment) in local currency, indexed to 2000=100.

Taken together, the advent of "cyber-physical systems" and their application equip people and machines with entirely new capabilities (see GII 2022 Expert Contribution from van Ark and Fleming). Nobel-prize winning economist William Nordhaus posits that computation and AI will eventually cross a boundary, beyond which economic growth will accelerate sharply, as an ever-increasing slew of improvements cascades through the economy (though he admits this is far from happening yet).[42]

Indeed, while the effect of ICT on non-ICT science and research has already been a forceful one, its effect in the second revolution and the required digital transformation will take a long time to materialize, given the complexity of application within a business context (see GII 2022 Expert Contributions from van Ark and Fleming; Petropoulos; Gültepe; Braga de Andrade, Cosentino and Sagazio).[43]

The reason for insufficient adoption to date is, in part, linked to the current limitations of installed computing and networking capabilities. However, it is caused principally by a lag in the adoption and integration of advanced second phase ICTs,[44] as well as the lack of a skilled workforce.

Even so, in selected high-tech firms within high-income economies, the positive productivity effects of the Digital Age wave can already be felt (see GII 2022 Expert Contribution from Peters and Trunschke).[45]

Clearly, although the figures for 2021 and 2022 fail to show a productivity upswing, experts remain convinced that the COVID-19 pandemic accelerated three things: (i) the accumulation of ICT-related capital; (ii) an increase of associated skills; and (iii) a spurring of organizational and behavioral changes – remote work being one of them, but also spilling into new, digital ways of delivering services previously subject to low productivity, for example, tele-medicine (see GII 2022 Expert Contribution from Mazumdar-Shaw), as well as tele-education. As a result, "a decade's worth of digital innovation has been compressed into just under two years, boosting innovation adoption."[46]

Deep Science wave: Life sciences and health, clean tech, and agri-food innovation
In addition to a reinvigorated Digital Age wave, there is the real possibility of another upcoming innovation wave – a Deep Science wave – evolving around breakthrough inventions and innovations in the fields of life sciences and health, agri-food, energy and clean tech, and transport. This wave relates to scientific progress across an array of scientific and technical fields,

outside of ICT, that have matured over the last decades, and which are erupting – see the rapid evolution of novel vaccines – or are about to erupt shortly.

Like the Digital Age, this Deep Science wave has not arrived out of nowhere. Breakthroughs in biotechnologies, bio-chemistry, nanotechnologies, new materials and other basic scientific advancements made over the last decades are now a lubricant for downstream innovations – representing a true comeback for the hard sciences.[47] Breakthroughs include:

- developments in genetics and stem cell research, nanotechnology, biologics and brain research generating new possibilities for the detection, prevention and cure of disease, including vaccines;[48]
- novel materials, such as new resins and ceramics, being developed at the nano-technology level, drawing on advancements in graphene and the material sciences, which promise to change production going forward (see GII 2022 Expert Contribution from Gültepe);
- an unprecedented convergence of biology, agronomy, plant science, digitalization and robotics transforming innovation in the field of agriculture and food.[49]

Beyond the use of ICTs alone, science is today being conducted with radically more efficient tools and processes. The indirect effects on productivity cannot be overestimated.[50] As a result, a previously feared stagnation in the field of biomedical sciences is now considered over.[51]

Taken together, this has led to radical progress in fields as diverse as life sciences and health, agri-food, energy and clean tech, and transport innovation (Table 11). In these fields, the links between big science, industrial innovation and the marketplace have become stronger rather than weaker.

Table 11 Deep Science wave impacts in four fields

Life sciences and health	Agri-food
New scientific breakthroughs, treatments, and cures	**New scientific breakthroughs**
Genetics and stem cell research	New-generation sequencing
Nanotechnology	Bioreactor-based synthetic food production
Biologics	Lab-grown real meat and other future foods with higher yields and better nutrient content
Brain research	Self-fertilizing crops
New generation of vaccines and immunotherapy	Precision farming
Pain management	Smart fertilizers
Mental health treatments	Advanced packaging
New medical technologies (precision and regenerative medicine)	Total recycling
	New food production systems
New health innovation systems	Digital agriculture enabled by remote sensing, and geographic information systems
Novel approaches in health care research (e.g., AI)	Bio-controlled and artificial agro-ecosystems
New ways of delivering health care (e.g., telemedicine)	Vertical farming
	Innovation along the agri-food value chain, from seeds to farming and harvesting
	Digitalization of retail and logistics
Energy and clean techology	**Mobility**
New scientific breakthroughs	**New scientific breakthroughs**
Cheaper and efficient renewable energies	Electric batteries and other elements of energy and clean tech
Battery technologies	Autonomous vehicles
Fusion technology	Tunneling for high-speed transport
Geothermal	Supersonic and electric aviation
Green hydrogen	
Sustainable alternative fuels	**New transport systems**
Carbon dioxide catcher	Charging infrastructure
	Urban air mobility companies
New energy delivery and storage systems	Drone delivery
Digitalization of energy system	Ultra-highspeed train networks
Smart grid	Novel traffic management systems
Ultra-high voltage lines	
Utility-scale storage of renewable energy	
Small-scale renewable systems to provide electricity to people living far from the grid	

Sources: GII 2019, 2018, 2017 and this volume, in particular GII 2022 Expert Contribution from Gutierrez de Piñeres Luna.

Still, a cautionary note is in order. The literature on innovation waves had predicted the life science wave would take over from the ICT wave in the 1990s – yet this did not happen. The transformative potential of technologies such as CRISPR, graphene and nanotechnology more broadly has been touted for at least two decades, if not three. And, although they have now been around for a long while, they have not led to a revolution. Again, in general, it is important to acknowledge the long lead times required and related uncertainties. Clearly, the pandemic may have inadvertently unlocked the potential of mRNA technology, with possible spillover effects to other areas of health. Factors like the greater frequency of environmental disasters or high energy prices might also have started to boost clean technologies in the short term.

The Digital Age and Deep Science waves: Which impacts on what sectors?

This cautionary note aside, one can nevertheless speculate about the impact the Digital and Deep Science waves are likely to make on different sectors of the economy. In Table 12, sectors are ranked by order of recent productivity growth rates in G7 economies.

Table 12 Promising new technologies identified by sector

	Digital Age wave impacts	Deep Science wave impacts	Welfare impact
Information and communication	Not applicable, originating sector	Yes, use of nanotechnology and neural networks	
Agriculture	Yes, in particular automation with regards to planting and harvesting, big data to make better decisions, etc.	Yes, see Table 11	Quicker delivery to market; reduction of carbon footprint; more sustainable
Manufacturing	Yes, in particular fields of automation, advanced robotics and 3D-printing	Yes, nanotech, new materials, etc.	
Wholesale and retail	Yes, in particular e-commerce and supply chain and logistics	Uncertain	
Finance and insurance	Yes, in particular FinTech, digital currencies; block chain	Uncertain	
Government	Yes, in particular e-government	Uncertain	
Transport and storage	Yes, in particular supply chain and logistics	Autonomous vehicles; supersonic aviation; urban air mobility companies; drone delivery; tunneling for high-speed transport, electric aviation	Fewer accidents; fewer carbon emissions
Real estate activities	More limited, except for planning and logistics, and virtual reality	Uncertain	
Arts, entertainment and other services	More limited, except for planning and logistics, and virtual reality	Uncertain	
Utilities	Yes, in particular smart grid	Yes, see Table 11	Cleaner and more abundant energy
Mining	Yes, for planning and extraction, and more advanced prospecting	Uncertain	
Professional, scientific, technical, administrative and support services	Yes, for collaborative telepresence, AI applications and machine learning	Uncertain	
Health and social care	Yes, including electronic patient records and remote health care	Yes, see Table 11	Improved well-being; longer and more healthy lifespan
Restaurants and hotels	More limited, except for delivery, planning and logistics, and robots	Uncertain	
Education	Yes, with virtual learning environments and distance education	Uncertain	
Construction	Medium with use in annex service industries (architects, etc.), such as integrated building information modeling	Yes, 3D-printed homes; materials science	

Source: Authors' analysis and conceptualization.

From the exercise in Table 12, some cautious conclusions can be drawn.

First, many of the likely productivity-enhancing innovations of the Digital and the Deep Science waves will positively impact those sectors performing above average in the last decade, including ICTs, agriculture, manufacturing, and wholesale and retail. These are important sectors of the economy, both in terms of employment and overall size. The possible impacts in fields such as automation for the various manufacturing sub-sectors, or the ability of some impacts to increase agricultural productivity, cannot be overestimated.

Second, the picture is more mixed, as regards those sectors in need of a productivity boost – it is unclear whether productivity laggards will be able to reverse their fortunes. Because the transport sector is large, economically speaking, it is probable that enhanced productivity in this sector could have a significant effect on productivity economy-wide. However, hospitality (restaurants and hotels) and other in-person type services might be unable to garner similar productivity gains from new waves of innovation. Any shift in demand from sectors where technology is progressing rapidly (e.g., manufacturing) to sectors where it is progressing slowly (e.g., services) reduces aggregate productivity growth.[52]

In sectors like construction, which has been plagued by low productivity growth in the past, or mining, where productivity performance is medium on average, the impact of innovation on productivity is hard to predict. Only time will tell whether scientific and technological advances will make an important difference to these sectors' productivity. There are encouraging signs regarding the role of AI in extractive industries or 3D-printing in housing, but the aggregate productivity effects in these sectors are still uncertain.[53]

Third, although the impact of innovation might be enormous on energy, green technologies, health care and education, the effect on immediate and measured productivity might be limited. It would therefore improve overall well-being, for example, by reducing the carbon footprint or facilitating a longer and healthier lifespan, rather than seriously impacting business or productivity performance. Clearly, in the longer term, the benefits of a healthier population and cleaner environment could well be felt in terms of higher productivity growth.[54] That said, these effects are diffuse and some more related to improved welfare rather than productivity impacts (see Techno-pessimist or techno-optimist?).

On balance, if adoption is high – and that is the crux of the matter – innovation-driven productivity growth propelled by the Digital Age and Deep Science waves could turn out to be high.

Innovation diffusion, adoption and international catch-up: Drivers and barriers

What are the novel adoption and diffusion drivers likely to determine the fate and fortune of the impending waves of innovation breakthrough?

Table 13 sets out the main drivers for and obstacles to diffusion, adoption and international innovation catch-up.

Overall, technology adoption and complementary innovations are potentially a critical stumbling block. There is a renewed urgency from innovation actors and policymakers to transfer technology into the marketplace and find practical, innovation-driven answers to ever-more urgent societal challenges. This is an evident boost to adoption. Yet, as set out in Table 13, the challenges preventing the rapid adoption of technologies and their complementary innovations happening are real.

The services provided by large IT companies have the power to disseminate methods, techniques, software and artifacts that increase the productivity of the economic activities that absorb them. Such companies disseminate the most relevant second-generation ICT solutions to the wider economy.

Aside from the many asymmetries listed, the question of whether only a few select superstar firms benefit from technologies is an interesting one to pursue.[55], [56] Indeed, it is the case that frontier firms manage to improve performance, while lagging firms struggle to keep up. Such cases show technology is capable of delivering productivity growth, leaving the question of how the positive uptake of technology can be broadened. As explained in the context of Brazil (see GII Expert Contribution from Braga de Andrade, Cosentino and Sagazio), the inability of the "long tail" of small and medium-sized firms of low productivity existing in emerging country economies to tap technology potential is a big problem.

Skills shortages are an additional serious hindrance to innovation waves materializing; and this concerns rich countries equally as much as poor ones, including in fields such as data science.

One also needs to be realistic about the radical nature of some elements of the Digital Age and Deep Science waves, which makes them in need not only of acceptance by society, but also the complementary infrastructure and substantial new regulatory frameworks that are a long time in the making.

Table 13 Innovation diffusion, adoption and international catch-up: drivers and barriers

Drivers	Barriers
What is the state of innovation diffusion and adoption?	**What is the state of innovation diffusion and adoption?**
1. Generally, new technologies diffuse into households and firms faster today than in the past (Comin and Hobijn, 2010) 2. Novel second ICT wave technologies such as AI are embedded in services readily purchased off-the-shelf from external providers 3. Generally, technology transfer from public labs to the marketplace – including via spin-offs and starts-up – is getting more efficient 4. COVID-19 and emergencies in the fields of health, climate change and food may have accelerated the diffusion and adoption of new technologies, including by increasing their social acceptance	1. Technology adoption – as opposed to simple diffusion – is still arduous and long, particularly with respect to the second ICT surge and the Deep Science wave 2. Achieving widespread technology diffusion and adoption, and hence overcoming the firm, sectorial and regional level gaps (see the Techno-pessimist or techno-optimist? section) is challenging 3. The dominance of "superstar" firms – winner-takes-all – might slow innovation adoption (the productivity slowdown's "dirty secret," according to Andrews, 2016) 4. Severe skills shortages slow the adoption of novel technologies 5. Current economic uncertainty and the rise in capital costs might limit private technology and complementary innovation investments 6. Innovations in the fields of health (genetic engineering), robots and AI, transport (autonomous vehicles) and bio-engineered food are radical and require societal acceptance, a complementary infrastructure and substantial new regulatory frameworks long in the making
What drives international innovation catch-up?	**What slows international innovation catch-up?**
1. Recent setbacks aside, knowledge and technology spreads much faster internationally than in the past, with globalized production and innovation networks leading to unseen, unconditional catch-up and convergence with the frontier (Patel *et al.*, 2021) 2. Generally, the competency of middle- and lower-income economies in integrating and adapting leading technologies is on the rise 3. Only a very few emerging economies themselves drive frontier innovations (essentially China and a few others), thus facilitating diffusion and adoption in these same middle-income economies, and possibly the production of more cost-effective technologies fit for other emerging economies	1. COVID-19 and recent geopolitical conflicts invite a scenario where de-globalization or reduced international knowledge flows slow catch-up 2. Reduced corporate income and lower government revenues in middle- and low-income economies, together with reduced access to financial markets, depress technology investment 4. A few economies, especially in East Asia, have managed to catch-up through technology adoption. Yet, most developing country firms are far behind the technological frontier and find it difficult to adopt technologies, particularly micro-enterprises and informal enterprises 3. Since COVID-19, many developing countries have experienced setbacks to their education and human capital base, accentuating existing skills shortages 4. Many of the novel breakthrough innovations – including of the Digital Age and Deep Science waves – are mis-aligned with developing country circumstances

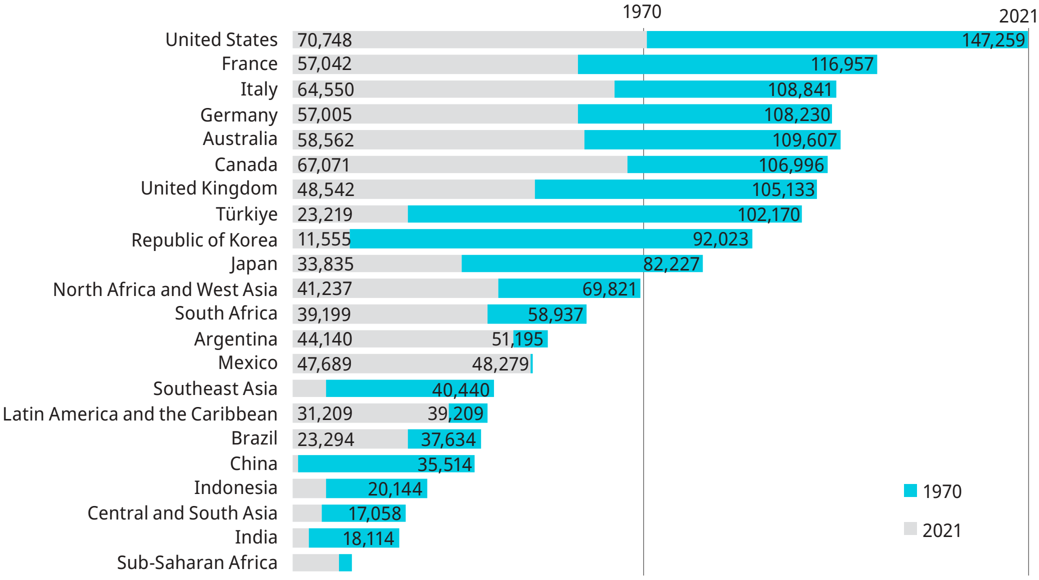
As to technological catch-up and convergence, the past three decades were an unacknowledged golden age that has led to unconditional and historic convergence.[57] This was thanks to increased globalization and what came with it in terms of knowledge diffusion and technology and innovation transfer, including managerial and other organizational and process innovations. All those countries that have climbed the GII innovation rankings over time, for example, China, India, Türkiye, the Philippines and Viet Nam, have for various reasons (e.g., industrial policies) been able to develop homegrown technological capabilities; an achievement reflected in measured innovation performance and the ability to participate in global value chains.

A key tailwind comes from the growing share of resources dedicated to R&D across the world over recent decades. The question of a possible decline in R&D productivity aside, this means that the financial and human resources devoted to solving the world's problems are clearly trending upwards.

It is also evident that, today, the proficiency with which middle-income countries are able to absorb existing technologies and innovations is far higher. This means that – at least for advanced developing countries like China – they are now in a position themselves to drive forward the technology frontier.

That said, the catch-up potential is still vast (Figures 22 and 23). Although convergence has quickened in some selected emerging economies, notably in Asia, such as China, India and Indonesia, but also Türkiye, the productivity differentials remain massive. As a case in point, an average hour worked in a middle-income economy produces goods and services worth around 10 to 20 percent of the value of what is produced in the United States. Impressively, if every country were to perform at the US level, global GDP would be nearly three and a half times its current size.

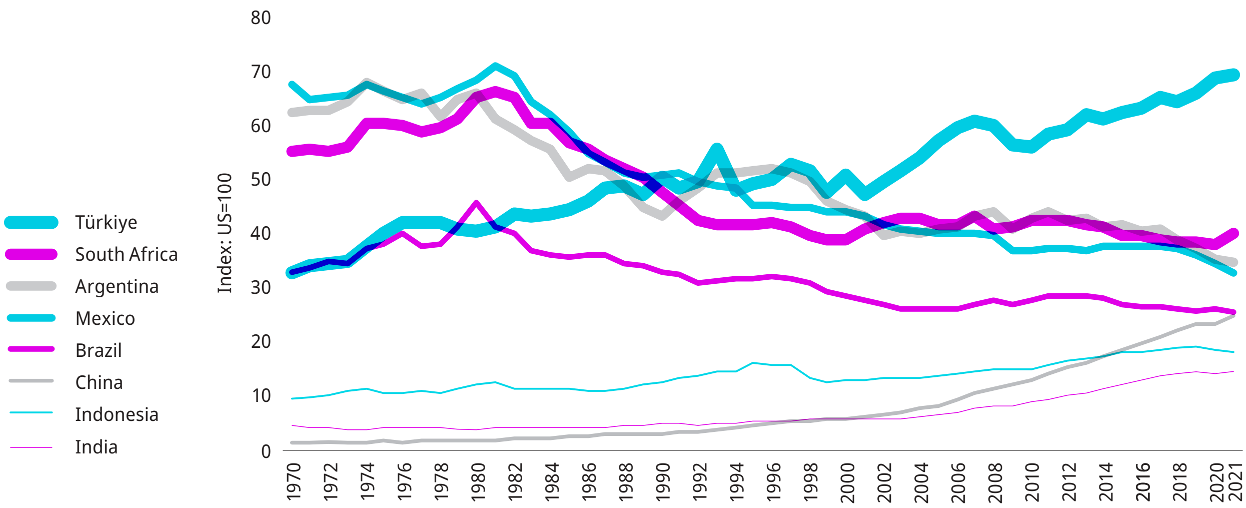
Figure 22 Productivity levels in selected major economies between 1970 and 2021



Source: Authors, based on data from The Conference Board Total Economy Database™ (April 2022).

Notes: Real GDP levels are expressed in 2021 international dollars, converted using purchasing power parity (PPP); productivity refers to GDP per worker.

Figure 23 Labor productivity relative to the United States



Source: Authors, based on data from The Conference Board Total Economy Database™ (April 2022).

Notes: Real GDP levels are expressed in 2021 international dollars, converted using purchasing power parity (PPP); productivity refers to GDP per worker.

And whether in the years to come there will be as much unconditional convergence potential as there has been over the last three decades is questionable. Countries that have yet to barely overcome the COVID-19 pandemic standstill are now confronted by geopolitical turmoil, as well as sizeable global trade and supply chain disruptions and a potential de-globalization scenario. This might close the door to any future emerging economy wishing to jump aboard the catch-up express train.

Finally, one must always keep in mind the question as to whether the outputs of the Digital Age and Deep Science waves are always a good fit for the needs and skills in place in developing countries.

Will innovation beat the slowing growth in living standards?

A decade ago, Gordon posited the need for faltering innovation to confront the significant headwinds slowing long-term growth in living standards, including an overhang of debt, aging populations, inequality and environmental policies that might (at least temporarily) be a drag on living standards, that is, per capita GDP growth (see Techno-pessimist or techno-optimist? section).[58]

Some of Gordon's arguments are rather US-centric, while others might need revision in the light of more current global events. In sum, some of Gordon's headwinds hold strong, some can be tempered, and new ones have emerged in the meantime.

- **Rising cost of inputs, energy and global value chain disruptions:** The COVID-19 pandemic and geopolitical events have resulted in steep rises in input costs and a shortage of goods and materials. There are growing calls for re-shoring or near-shoring, possibly heralding yet higher input costs. Whether higher input costs and energy prices are a temporary headwind is uncertain.
- **Public debt making future investments more difficult:** Debt levels surged during the pandemic, as governments sought to mitigate the negative impacts of shutdowns. These are expected to abate in advanced economies through to 2027, but expected to rise in emerging economies.[59] In general, it will be important to observe whether the cost of capital – and thus investment costs – persistently trend upwards over the coming years.
- **An aging population and shrinking workforce:** With global population growth rates shrinking, due to an aging population, the working-age population is either already contracting or expected to decline in many economies, both advanced and emerging. According to United Nations projections, the share of elderly people over 65+ years of age is expected to increase to almost 15 percent in 2040, up from 10 percent in 2020. The process of population ageing is especially acute in Europe and China. However, the concern that this will inevitably slow down economic growth, due to fewer people working, is not necessarily true. The example of Japan, and to some extent many European countries, shows that an ageing population does not have to result in a decline in labor force participation. Japan heads the world in terms of ageing, yet its employment levels have been increasing for the last two decades, due to increased participation rates. Put simply, ageing and a shrinking working-age population do not translate one-to-one into slower growth.
- **Rising income inequality:** Another headwind is rising inequality, meaning that even if an economy grows, the benefits do not reach a large segment of the population. Over time and across the world, income gaps have widened in advanced and emerging economies alike.[60] For example, the cumulative real income growth for the bottom 50 percent in the United States since 1976 through to the beginning of 2022 has been 34 percent, compared to 94 percent for the total economy.[61] At the same time, global inequality levels, that is, income inequality between countries, have decreased substantially over the last two to three decades.[62]
- **New regulations or policy ambitions in the field of environmental legislation that – temporarily – increase production costs:** The final headwind slowing a growth in living standards is the shift to a carbon-neutral economy. The main concern here is that such a shift raises the cost of production (for example, CO_2 emissions, once cost free, now come at a price), while also causing upheaval in the economy through stranded assets and plants, as well as jobs that need reallocation.[63] However, this could be considered a static view, with many advocates suggesting that, in the medium-term, green growth will boost rather than reduce economic growth. Moreover, avoiding major climate catastrophes will have positive welfare impacts beyond productivity.

Business and policy practices to release the next wave of productivity growth

This year's *Global Innovation Index 2022* Special theme written by notable innovation experts (available online), together with the section Revival or stagnation?, charts a possible positive trajectory for innovation-led productivity growth. However, both underline that a positive scenario is by no means certain. Indeed, a number of things still need to fall in place, if there is to be a new wave of innovation-driven growth.

It must be acknowledged that future technological opportunities are unpredictable, and so too their likely success in the marketplace. Consequently, there is great uncertainty around how productivity growth will evolve over the coming decades. There is also increasing perplexity regarding the question of how far governments should go, when trying to pick technology "winners" – an idea taboo in economic policy spheres until recently.

However, all are agreed that, given the technological opportunities out there, government policy has a role in ensuring they are realized. As outlined in what follows, this role ranges from funding basic and more applied research in promising fields to facilitating more fluid technology transfer and adoption (including via the creation of complementary infrastructure) to addressing inequalities at the firm, region and country levels, as well as closing important skills gaps and other key policy priorities.

The business and policy practices required for this are numerous and challenging. They run all the way from boosting frontier innovation and related funding to diffusion and adoption. And, what is more, the sectorial and technological specificities are enormous; for instance, transforming health systems with radical innovations is dauntingly different to transforming the transport system.[64]

Still, beyond general innovation policy prerogatives, there are several priorities that can be identified:

Funding breakthrough innovations and providing business incentives: An evident role of government remains the funding of research relevant to future innovation waves. However, there is a twist to this: increasingly, governments are being called upon to once again steer research and innovation toward solving rapidly important societal challenges, including via the creation of focused research institutes (see GII 2017 for agricultural innovation), mission-oriented funding, moonshot projects and R&D subsidies or tax breaks with a specific purpose in mind, and generally financing innovation (see GII 2020 as in Guadagno and Wunsch-Vincent, 2020). Any new government support mechanisms will need to specifically spur collaboration across innovation actors – including international partnerships.

Translation and adoption: In all future innovation waves, policymakers need to influence the translation and adoption of research in applications not only through supply, but also increasingly demand-side policies that set innovation targets and focus on specific areas that can no longer be left to the marketplace alone. The key challenge is how to overcome any incumbent model, like the fossil fuel-based infrastructure, installed vehicle base, commercial interests and regulatory and other infrastructure preventing energy innovation adoption (see GII 2018). Ensuring that disruptive forces can deploy and are not unnecessarily stalled is one essential ingredient. Increasingly, the public sector is also being expected to put in place smart demand-side policies – via public procurement and co-financing, for example. Yet again, access to finance remains the perennial stumbling block; the financial system is still rarely found to be fit for purpose in terms of providing innovation finance without tangible collateral (see also GII 2020 and GII 2022 Expert Contribution from Dosso).[65]

Establishing complementary infrastructure: The introduction of disruptive innovations often requires the presence of novel forms of hard or soft infrastructure: for example, the smart grid or electric vehicle charging stations for energy innovation or digital health networks (and mobile internet penetration) or new imaging standards for medical innovation.

Addressing inequality and fostering competition: Rising inequality between leading and lagging firms, leading and lagging regions, across high-paid and low-paid workers, and across countries is recognized as a major drag on technology diffusion, adoption and productivity. Tackling these differences will be key to realizing the benefits of any upcoming innovation waves. The policies proposed to achieve this are multi-faceted. One policy proposal relates to how to deal with the so-called superstar technology firms and possible ways of maintaining or fostering competition.[66] Yet, the hegemony of such firms is unlikely to be the sole reason for the disparities outlined earlier (see Techno-pessimist or techno-optimist?), and for which other policy instruments are required.

Urgently narrowing the skills gap: A skills gap stands in the way of new innovation waves materializing and creating impact. This is most evident in the fields of advanced ICT, programming, AI and data science skills, and is valid even in the most advanced high-income economies. ICT skills of this type and skills in digital technologies are required, including for digital innovation in the agricultural sector and for many developing country innovations. Similar skills gaps will become evident in fields related to the Deep Science wave, too.

Data infrastructure and management: The access, management and valorization of data is a cornerstone of all future innovation waves. New data infrastructure and data management systems will be important. Some dangers exist, like the monopolization of data by a few firms.[67] Regulatory frameworks fostering trust and privacy in fields such as transport and health care, but also in others, are an important driver fostering innovation adoption (see GII 2019 as in Dutta *et al.*, 2019), and GII 2022 Expert Contribution from Mazumdar-Shaw).

Fostering debate and societal acceptance: Over the coming years, topics such as humanoid robots, AI, bio- or genetic engineering, new health solutions, and novel food types will challenge social acceptance and therefore require societal debate. Debating risks, social values and the pros and cons of novel innovations will all be key to facilitating innovation adoption.

Keeping international learning and technology flows lively: The current international environment poses real challenges to the diffusion of technology via trade, investment and other international knowledge flows. This is particularly problematic for emerging and developing countries in dire need of integrated global value chains and innovation networks in order to catch-up. Keeping alive the possibility of quick productivity wins will be crucial.

Developing countries face barriers to using existing technologies for their own economies: Developing economies will need to take a specific approach to absorbing existing technologies – particularly in health and agriculture. In this respect, the acute barriers faced in developing countries with regards to funding for both public and corporate R&D are a concern, as are limitations to entrepreneurship or business sector innovation in general (see GII 2022 Expert Contribution from Dosso, on required funding for prototyping, demonstration activities and market expansion). Skills are important too (see above), but their need extends beyond technical or research skills, often relating to marketing and managerial skills.

The fostering of grassroots and incremental innovations, and how to make traditional innovation policy measures more relevant to less formal innovation is an important factor in this context. Local governments and firms need to steer the development of innovations fit for local contexts – rather than relying on diffusion alone. In the field of health, for example, low-tech or adapted technologies are already saving more lives than the latest high-tech innovations (see GII 2019 as in Dutta *et al.,* 2019).

Important measurement priorities: To get a firmer grip on understanding and supporting innovation-driven productivity growth, more work is required on better measurement, as well as a stronger focus in the productivity data in official data releases (as is already evident in the United States and the United Kingdom). In particular, better metrics are required for assessing the extent of frontier innovation, related diffusion, installment and absorption. The contemporary data arsenal for capturing technology diffusion and adoption at the firm and societal level – broadband and mobile network coverage aside – is, at best, poor.[68]

To underpin our understanding of the role of related investments and productivity, here are three suggestions:

(i) work toward the better measurement of intangible assets, in particular so as to better cover the full spectrum of these assets, including design, product development and economic competencies, as well as brand, organizational capital and training, which are all still treated as intermediate inputs and thus go unmeasured;
(ii) better measure the digital economy, particularly digital service investments (including cloud computing), which are likewise treated as intermediate inputs; and
(iii) better capture quality improvements, both within and outside of ICT.

Finally, if innovation today is more oriented toward solving urgent challenges rather than merely driving enterprise productivity (see Techno-pessimist or techno-optimist?), the linkage between innovation and productivity gains will, unsurprisingly, become weaker. Ultimately, this requires better metrics for measuring those innovation impacts that can be felt beyond firm-level productivity.

Conclusion

Following decades of slow productivity growth and faltering innovation potency, evidence is building for the existence of two types of novel innovation waves, each potentially having large productivity and welfare impacts – the Digital Age wave and the Deep Science wave.

However, the positive effects of these waves will take a long time to materialize; numerous obstacles, particularly in the area of technology adoption and diffusion, have to be overcome. Digital Age innovation and its advanced ICT solutions need to increase their sophistication, if they are to substantially increase productivity in the services sector.

It is also uncertain whether existing productivity metrics are up to capturing the potency of innovation. Many societal preoccupations, and many of the impacts of novel Digital Age and Deep Science innovations, are focused on well-being, including health, better education, the environment and housing. But they do not necessarily accord with the established productivity concept of producing more with less. This requires a fundamental rethink about how we measure innovation impacts and outcomes – a fertile field for future innovation measurement and policy work.

Notes

1 This piece draws on a longer background study for the GII 2022 Special theme as per de Vries (The Conference Board), and earlier submissions by Francesca Guadagno (Consultant), on past and present innovation waves (both unpublished background studies) and the WIPO workshop “Global Innovation Index 2022: What is the future of innovation-driven growth?” held on May 2, 2022, with a presentation of all the Expert Contribution authors. Marco Alemán, Charlotte Beauchamp, Carsten Fink, Bruno Lanvin and Samar Shamoon provided useful comments to an earlier draft.

2 WIPO, 2015.

3 Data for 1300–1950 are from the Maddison Project Database 2020. 1950–2021 data taken from The Conference Board Total Economy Database™ (April 2022). This approach follows Gordon (2012). Real GDP levels are expressed in 2021 international dollars, converted using purchasing power parity (PPP); frontier refers to England, Great Britain and the United Kingdom from 1300–1879 and the United States from 1880 onwards.

4 The G7 consists of Canada, France, Germany, Italy, Japan, the United Kingdom and the United States.

5 WIPO, 2015; DeLong, 2022.

6 Perez, 2002.

7 Fleming, 2021.

8 WIPO, 2011. In theory, the further a country is from the frontier the faster the catch-up. Yet, this is not as automatic as economic theory would imply. It takes time and the availability of skills and resources – absorptive capacity – in less developed countries, and perhaps most importantly, a policy environment conducive to competition. These spillovers are frequently driven by knowledge acquired through channels such as foreign direct investment (FDI), trade, joint venture multinationals, migration and/or collaboration with firms from higher-income countries.

9 WIPO, 2015.

10 Brynjolfsson and Petropoulos, 2021.

11 Trend growth rates are obtained using a HP (Hodrick-Prescott) filter, assuming lambda (λ)=500.

12 High-income OECD economies are Australia, Austria, Belgium, Canada, Chile, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Republic of Ireland, Israel, Italy, Japan, Latvia, Lithuania, Luxembourg, Netherlands, New Zealand, Norway, Poland, Portugal, Slovak Republic, Republic of Korea and the United States.

13 See GII, 2021; WIPO, 2015, 2019, 2021b.

14 Bloom *et al.*, 2020.

15 Bloom *et al.*, 2020.

16 Bloom *et al.*, 2020; Collison and Nielsen, 2018; Cowen and Southwood, 2019.

17 Gordon, 2012.

18 See also WIPO, 2015.

19 Cowen, 2020.

20 Arundel *et al.*, 2021.

21 Arora, Belenzon and Patacconi, 2018.

22 Gordon, 2012.

23 Philippon, 2022.

24 Cowen, 2020; Cowen and Soutwood, 2019; Brynjolfsson *et al.*, 2021; *The Economist*, 2020. See also the conference “Is the Great Stagnation Over?,” hosted by the American Enterprise Institute in April 2021.

25 McKinsey Global Institute, 2018.

26 World Bank 2021, chapter 7.

27 See also Charmes, 2016.

28 Van Ark in the WIPO workshop on “Global Innovation Index 2022: What is the future of innovation-driven growth?” held May 2, 2022.

29 Data are for 2020, except for Japan (2016), China (2017) and Colombia (2018); data for Spain exclude Basque Country, Navarra, Ceuta, Melilla and the Canary Islands; data for France exclude Corsica, Guadeloupe, Martinique, French Guiana, La Reunion and Mayotte.

30 Coyle, 2015.

31 Brynjolfsson *et al.*, 2021.

32 Byrne *et al.*, 2017.

33 Lipsey *et al.*, 2005; Vollrath, 2020.

34 The digital revolution has fundamentally altered the way we consume (increased variability, ease of access) and work, in ways not captured within productivity statistics. Consider the consumption of music, for example, where streaming services nowadays offer easy access to an endless variety and enormous quantity of music, from the latest hits to compositions by Bach or Mozart.

35 Kapoor and Debroy, 2019.

36 Greene, 2021; *The Economist*, 2020.

37 The Conference Board Total Economy Database™, Productivity results (April 2022), available at: https://www.conference-board.org/press/productivity-brief-2022.

38 The Conference Board Total Economy Database™, Productivity results (April 2022), available at: https://www.conference-board.org/press/productivity-brief-2022.

39 The Conference Board Total Economy Database™, Productivity results (April 2022), available at: https://www.conference-board.org/press/productivity-brief-2022.

40 Kondratieff, 1935; Perez, 2002; Wilenius, 2014; Allianz, 2010; WIPO, 2015 (in particular infographic “200 years of Innovation and Growth”, available at: https://www.wipo.int/export/sites/www/pressroom/en/documents/wipr_2015_infographic.pdf).

41 Cockburn *et al.*, 2018. Vickery and Wunsch-Vincent, 2008.

42 Nordhaus, 2021.

43 Van Ark, 2016, who calls this the gestation period for technologies in the “New Digital Economy.”

44 Zolas *et al.*, 2020.

45 Van Ark *et al.*, 2020.

46 Brynjolfsson and Petropoulos, 2021

47 WIPO, 2015.

48 GII, 2019.

49 See GII, 2017.

50 Mokyr, 2016; Brynjolfsson *et al.*, 2017.

51 See Cowen, 2020 and GII, 2019 on the revival of health care research productivity.

52 Bauer *et al.*, 2020, on the role of services in the Europe productivity growth slowdown. For an overview of productivity growth in US manufacturing, see Brill *et al.*, 2018.

53 Daly *et al.*, 2022, on innovation in the mining sector.

54 WIPO, 2015, Figure 1.5 and text on page 27.

55 Evidence shows that a very large proportion of the R&D investments financed and executed by the business sector worldwide is concentrated in a relatively small number of world-leading corporate innovators, in many cases large multinational groups (see also the GII 2021 Tracker).

56 See also De Loecker *et al.*, 2022; Cirera *et al.*, 2020.

57 Patel *et al.*, 2021.

58 Gordon, 2012.

59 IMF, 2022.

60 World Inequality Database, available at: https://wid.world.

61 See https://realtimeinequality.org for the underlying data.

62 World Inequality Database, available at: https://wid.world.

63 See https://www.piie.com/publications/policy-briefs/climate-policy-macroeconomic-policy-and-implications-will-be-significant.

64 See the 2017, 2018 and 2019 editions of the *Global Innovation Index* and Atkinson, 2016.

65 Erber *et al.*, 2017.

66 De Loecker *et al.*, 2022.

67 Cockburn *et al.*, 2018

68 Zolas *et al.*, 2019; Cirera *et al.*, 2020.

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