Global Innovation Tracker

What is the global state of innovation? Just how fast is the pace of technological progress and adoption, and what are the related impacts?

This section of the GII provides the most recent insights into these questions supported by the latest innovation data.

Global Innovation Tracker Dashboard

Science and innovation investments

	Scientific publications	R&D expenditures: Total	R&D expenditures: Business	R&D expenditures: Top corporate R&D spenders	International patent filings	Venture capital deals	Venture capital value
Short term	8.3% 2020 → 2021	3.3% 2019 → 2020	3.5% 2019 → 2020	9.8% 2020 → 2021	0.9% 2020 → 2021	46.0% 2020 → 2021	125.5% 2020 → 2021
Long term	5.7% 2011 → 2021 (annual growth)	4.6% 2010 → 2020 (annual growth)	5.5% 2010 → 2020 (annual growth)	n.a.	4.3% 2011 → 2021 (annual growth)	7.3% 2011 → 2021 (annual growth)	23.6% 2011 → 2021 (annual growth)

Technological progress

	Microchip transistor count	Electric battery price	Costs of renewable energy generation: Solar photovoltaic	Costs of renewable energy generation: Wind	Drug approvals
Short term	21.4% 2019 → 2021	–5.7% 2020 → 2021	–7.0% 2019 → 2020	–12.5% 2019 → 2020	–5.7% 2020 → 2021
Long term	36.5% 2011 → 2021 (annual growth)	–17.9% 2011 → 2021 (annual growth)	–17.3% 2010 → 2020 (annual growth)	–7.5% 2010 → 2020 (annual growth)	5.2% 2011 → 2021 (annual growth)

Technology adoption

	Broadband: Fixed	Broadband: Mobile	Robots and automatization	Electric vehicles
Short term	5.7% 2020 → 2021	7.6% 2020 → 2021	10.4% 2019 → 2020	61.1% 2020 → 2021
Long term	6.9% 2011 → 2021 (annual growth)	17.3% 2011 → 2021 (annual growth)	11.0% 2010 → 2020 (annual growth)	74.0% 2011 → 2021 (annual growth)
Penetration	16.7 of 100 inhabitants in 2021 (15.8 in 2020)	83.2 of 100 inhabitants in 2021 (77.3 in 2020)	n.a.	1.4 of 100 cars in 2021 (0.8 in 2020)

Socioeconomic impact

	Labor productivity	Life expectancy	Carbon dioxide emissions	
Short term	0.0% 2020 → 2021	–0.02% 2019 → 2020	–5.2% 2019 → 2020	4.9%* 2020 → 2021
Long term	2.3% 2011 → 2021 (annual growth)	0.3% 2010 → 2020 (annual growth)	0.4% 2010 → 2020 (annual growth)	

Notes: See the Data notes at the end of this section for a definition of the indicators and their data sources. Long-term annual growth refers to the compound annual growth rate (CAGR) over the indicated period. Historic data may have been updated and can differ from last year's Global Innovation Tracker. Estimates are indicated by *.

What is the current global state of innovation? Have the combined effects of the COVID-19 pandemic, more recent geopolitical tensions and tighter monetary policies slowed or accelerated investments in innovation? How fast is the pace of technological progress and technology adoption? What are the socioeconomic impacts of scientific progress and innovation?

The Global Innovation Tracker – introduced for the first time in the *Global Innovation Index* (GII) last year – addresses these questions and offers an insight into the global state of innovation.[1] It captures key innovation trends within four broad stages of the innovation journey: science and innovation investments; technological progress; technology adoption; and the socioeconomic impact of innovation.

The main findings this year are as follows:

1. Contrary to what historic evidence would suggest, *science and innovation investments* were thriving at the height of the COVID-19 pandemic and boomed in 2021, but their continued resilience is uncertain for 2022 in the face of new challenges.

2. The indicators of *technological progress* in the fields of semiconductor speeds, electric battery prices, the cost of renewable energy (with the exception of wind) and drug approvals show a significant slowdown from long-term trends, and even a decline in the case of drug approvals.

3. *Technology adoption* is progressing, with positive growth rates across technologies measured by the Global Innovation Tracker, and in particular for electric vehicles. However, penetration rates are still medium to low, with the exception of mobile broadband, which reaches the vast majority of the global population.

4. Largely due to the short-term influences of the COVID-19 pandemic, the *socioeconomic impact* of innovation seems to be at a low point, with labor productivity and life expectancy experiencing a significant slowdown if not coming to a complete standstill, and in the case of carbon dioxide emissions, failing to show ongoing reductions in pollution.

Science and innovation investments

Contrary to what historic evidence would suggest, *science and innovation investments* were thriving at the height of the COVID-19 pandemic and boomed in 2021, but their continued resilience is uncertain for 2022 in the face of new challenges.

Global output first declined by 3.1 percent in 2020, recovered strongly by an estimated 6.1 percent in 2021 and is expected to contract again to a projected 3.2 percent growth in 2022 due to geopolitical turmoil, supply chain disruptions and other challenges.[2]

Global output and investments in research and development (R&D) tend to experience booms and busts simultaneously. Historic data, viewed in isolation, would have led us to expect a prompt cutback in science and innovation investments, intellectual property filings and venture capital in 2020 and 2021.

However, the economic developments seen between 2020 and 2022 cannot be viewed in the context of a “business as usual” cycle. Rather, two external shocks of historic proportions have taken place: a global pandemic leading to a prolonged, worldwide economic standstill and then, just as the recovery was strongly underway in 2021, the conflict in Ukraine, which has had significant global economic impacts.

Nevertheless, the key indicators of global science and innovation investments – scientific publications, R&D expenditures, international patent filings and venture capital deals – remained strong in 2020 and in 2021. In particular, venture capital has boomed, albeit to different degrees according to country and sector.

Early indications in 2022, however, point to possible challenges to come. While innovation was resilient in 2020 and flourishing in 2021, in line with the global recovery, the second external shock coming so soon afterwards, together constituting a real double-whammy, might be more complicated to overcome.

Scientific publications

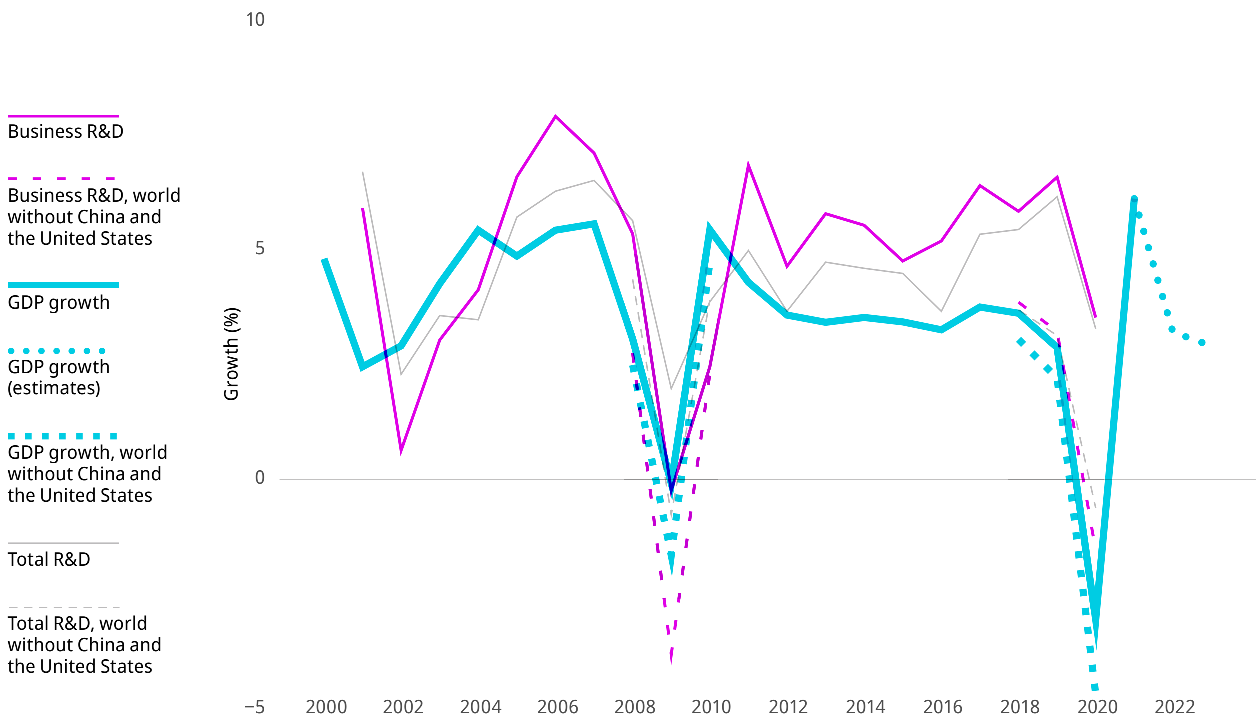
The number of scientific articles published worldwide continued to grow steadily throughout the height of the pandemic and during 2021, surpassing the 2 million mark for the first time in 2021, representing a year-on-year growth rate of 8.3 percent (see Dashboard). This growth rate is notably higher than its long-term trend of 5.7 percent growth, indicating that scientific research is at its most vibrant.

Research priorities have further shifted to public, environmental and occupational health, with record growth of 19.9 percent in 2021, digital technologies, such as artificial intelligence, which have consistently achieved double-digit growth since 2018 (+21.2 percent in 2021), and environmental topics.

R&D expenditures

The year 2020 was an exceptional one for R&D investments. Specifically, investments in global R&D in 2020 have continued to grow at a rate of 3.3 percent, down from 6.1 percent in 2019. Business R&D expenditures – the most significant component of total global R&D – grew by 3.5 percent in 2020, down from 6.6 percent in 2019 (Figure 1).

Figure 1 **The usual correlation of R&D and GDP growth, 2000–2023**



Source: WIPO estimates, based on the UNESCO Institute for Statistics database, Organisation for Economic Co-operationand Development (OECD) Main Science and Technology Indicators (March 2022), Eurostat, Ibero-American and Inter-American Network of Science and Technology Indicators (RICYT) and the International Monetary Fund's World Economic Outlook Update, July 2022.

Three out of the top five R&D spending economies in 2020 experienced significant R&D growth: the United States (+5 percent), followed by China (+9.6 percent), Japan (−2.7 percent), Germany (−5.3 percent) and the Republic of Korea (+3.2 percent), in order of the overall R&D budgets.

Apart from China, Türkiye is the only other middle-income economy that registered growth in total R&D and business R&D in 2020, with increases of 4.2 and 5.2 percent, respectively. Other middle-income economies for which data are available that increased their total R&D in 2020 include Armenia (8.5 percent), Azerbaijan (7.3 percent), Kazakhstan (3.8 percent), Indonesia (1.4 percent) and Serbia (1.2 percent).

However, 2020 data are still unavailable for some of the larger R&D spenders among the middle-income economies, such as Brazil, India, Malaysia, South Africa and Viet Nam.

The effects of the pandemic and other turmoil on the R&D budgets of low- and middle-income economies are currently largely unknown. Global R&D totals are certainly heavily influenced by the spending of the top R&D nations, such as the United States and China, possibly masking country-specific R&D cuts. Without these two major players, total global R&D would have fallen by –0.6 percent (down from 3.3 percent) in 2020 and business R&D to –1.6 percent (down from 3.5 percent) – see the dotted lines in Figure 1 – further underlining the vital role played by China and the United States – and also, of course, other major economies, such as Germany, Japan and the Republic of Korea – in global R&D.

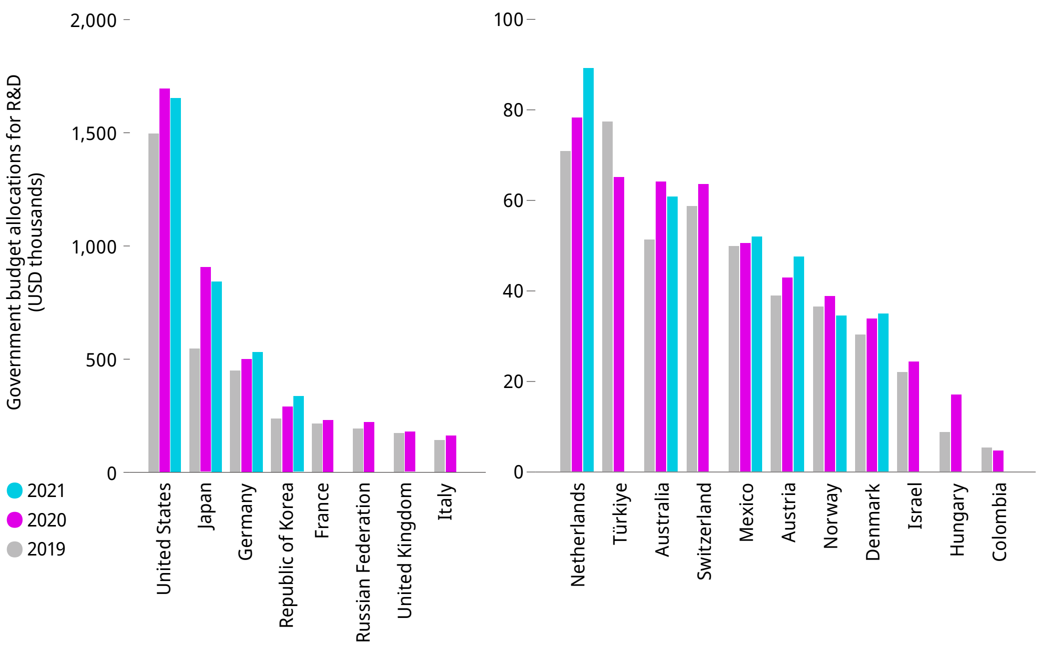
Official R&D data for the full 2021 calendar year will only be available by the first half of 2023 and it will be presented in the next edition of the GII, with full data on R&D in 2022 available in 2024.

To get a sense of what to expect for 2021 and 2022, one can look, first, at governments' planned R&D budgets and, second, at company data on yearly and quarterly R&D expenditures for 2021 and early 2022. These are imperfect proxies but they are the best available.

Supporting the overall global R&D increase mentioned above, government budget allocations for the top R&D spending economies showed continued, and sometimes strong, growth in 2020, with growth strongest in Hungary (+100 percent), Japan (+65 percent), Australia (+25 percent), Republic of Korea (+22 percent) and overall growth throughout, with the exception of Türkiye and Colombia (see Figure 2).[3]

For those economies that have already disclosed their planned 2021 R&D budgets, the picture is less clear (see Figure 2), with spending continuing to grow for the Republic of Korea (+15 percent), and Germany (+6 percent) – among the top spenders – and the Netherlands, Austria and Mexico among the smaller R&D spenders. However, not only Japan (–7 percent) and the United States (–3 percent) – two of the top five global major R&D spenders – but also Australia and Norway see declines, albeit smaller than the planned increases of 2020, indicating a positive overall level for 2021 relative to 2019.

Figure 2 **Government budget allocations for R&D, 2019, 2020 and 2021**



Source: WIPO, based on joint OECD–Eurostat data collection on resources devoted to R&D, July 2022.

Notes: Figures are in current US dollars purchasing power parity (PPP). The 2020 figure may differ slightly from that in the GII 2021 Tracker as it has been updated to include additional countries as more data became available. Note that these data are not available for China.

Government R&D expenditures have therefore mainly expanded in 2020, possibly to counteract anticipated business R&D busts, which, in the end, never happened. The year 2021, in turn, should see a slowdown in government R&D budget growth but WIPO estimates still indicate positive growth, although this prediction is made on the basis of highly incomplete data.

Again, the interesting question is really how the R&D budgets of emerging R&D countries have fared, and whether a positive trajectory that started in the 2010s might have come to a halt due to the pandemic, including in African and Latin America.

On the corporate side, R&D investment data are available for around 1,700 of the top 2,500 largest corporate R&D spenders worldwide.[4]

Overall, this sample of top corporate R&D spenders increased their R&D expenditures by around 10 percent to over USD 900 billion in 2021 (see Table 1), which is slightly higher growth than the year before the pandemic (2019), and just over 1 percentage point lower than growth in 2020.[5] For these firms, revenues decreased by 0.5 percent in 2020 and then rebounded by 17.7 percent in 2021.

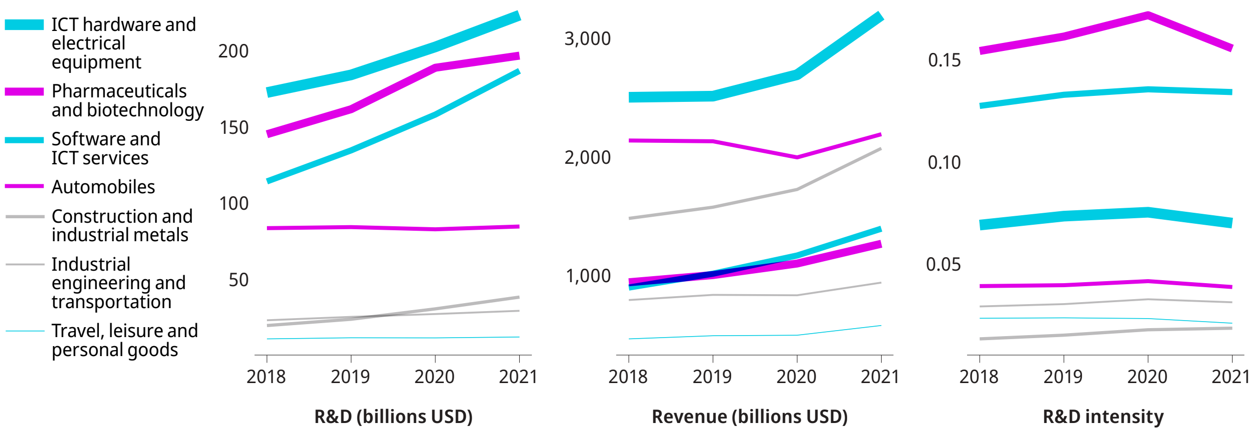
Table 1 R&D and revenue growth of the top global corporate R&D spenders, 2018–2021

	R&D		Revenue		R&D intensity	
Year	Billions USD	Growth (%)	Billions USD	Growth (%)	Ratio	Growth (%)
2018	675		15,947		0.042	
2019	739	9.4	16,297	2.2	0.045	7.1
2020	823	11	16,222	–0.5	0.051	11.8
2021	903	9.8	19,086	17.7	0.047	–6.7

Source: WIPO, based on Bureau van Dijk (BvD) Orbis database.

However, these figures mask large differences at industry level. Figure 3 presents annual R&D expenditures, revenues and R&D intensities for the seven industries with the greatest cumulative R&D investment in 2021. Similar to last year the increase in R&D expenditures between 2018 and 2021 – shown in Table 1 – is primarily driven by four industries: namely, ICT hardware and electrical equipment; pharmaceuticals and biotechnology; software and ICT services; and construction and industrial metals.[6] These industries also experienced an increase in revenues, causing their R&D intensities to remain relatively unchanged.

Figure 3 R&D expenditure and revenue totals of top global corporate R&D spenders, by industry and year, 2018–2021

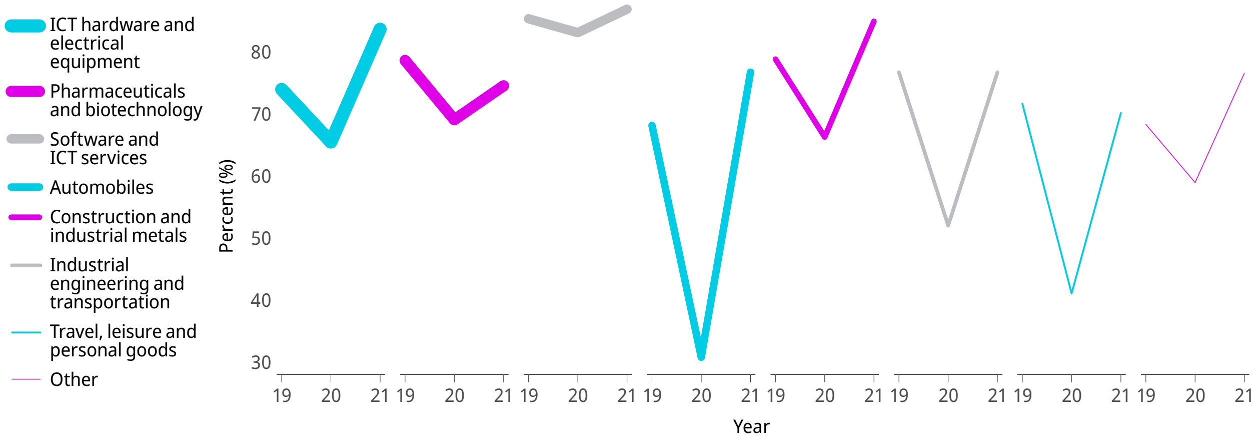


Source: WIPO, based on BvD Orbis database.

With respect to the share of firms experiencing R&D expenditure increases, all industries rebounded to near pre-pandemic levels, as shown in Figure 4.

All R&D expenditure curves display a characteristic "V" shape – a fall of R&D growth in 2020 and a strong rebound in 2021, with automobiles, industrial engineering and transportation, and travel, leisure and personal goods experiencing "deep-V" patterns. Sectors that were severely depressed in 2020 rebounded strongly again, with the share of automotive firms that increased their R&D rising from 31 to 77 percent, the travel, leisure and personal goods industry going up from 41 to 70 percent, and those firms which were leading in the fields of ICT hardware and electrical equipment and pharmaceuticals and biotechnology last year rising further from already high levels. However, separate calculations show that only software and ICT services saw an increase in their share of firms with R&D intensity growth.

Figure 4 Share of top corporate R&D spenders reporting R&D expenditure increases, 2019–2021



Source: WIPO, based on BvD Orbis database.

The differential impact of the pandemic is also evident in the R&D performance of individual companies. Figure 5 presents the percentage change in R&D expenditure for the top 15 firms within the top seven industries and "Other" with data available. The solid black vertical lines indicate the annual mean by industry.

Generally, companies which stood to gain from pandemic-induced shifts in demand increased their R&D efforts in 2021. These include semiconductor chip makers, such as Nvidia, Qualcomm, SK Hynix and Intel, internet companies, such as Facebook, Baidu, Salesforce and Netflix, and many of the large pharmaceutical companies with successful COVID-19 vaccines, such as AstraZeneca, Pfizer and Johnson & Johnson. Notably, within the construction and industrial metals industry, the majority of the top 15 firms are Chinese, suggesting that the development of capital-intensive projects was largely unaffected by the pandemic within China.

The differences within sectors are intriguing and worthy of further study, such as the R&D spending surges of BMW while Mercedes (Daimler) saw hefty R&D cutbacks.

In contrast, those companies whose business models rely on in-person activities or travel decreased their expenditures, including Airbnb, Airbus, Boeing, Uber and many automobile manufacturers.

The data shown in Figure 5 are heavily biased toward top R&D performers – the "R&D superfirms." A fuller assessment of corporate R&D performance in light of the crisis will have to wait for more data to become available, including that from small and medium-sized enterprises that may have experienced harsher conditions for innovation finance in 2020 and 2021.

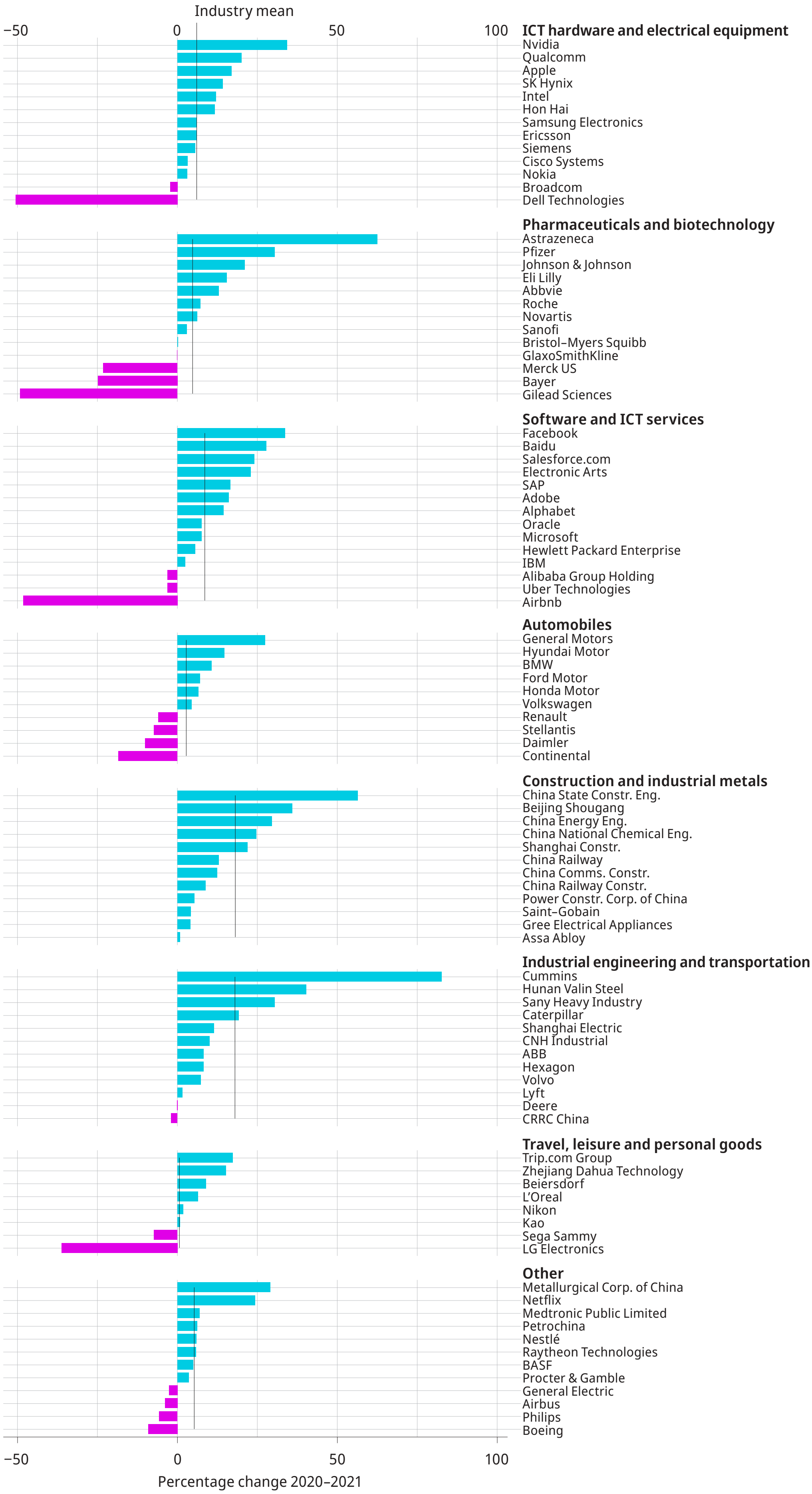
Intellectual property filings

During previous crises, international patent filings – so-called filings via the Patent Cooperation Treaty (PCT) of WIPO – declined in line, to varying degrees, with economic output.[7] Organization-wide budget cuts, specific pressure on corporate intellectual property (IP) budgets, curtailed innovation financing and subdued startup activity were the main transmission channels through which reduced output impacted IP filings in the past.[8]

In contrast, IP filing activity, including patents, trademarks and designs filed at the international level, has increased during the global pandemic, in spite of the 2020 recession.[9] In terms of patents, the 2020 crisis saw declines, albeit more muted than in the wake of the crisis in the early 2000s (the dot-com bubble) and the Great Recession of the late 2000s, during which international patent filings actually declined.[10] International patent filings grew by 0.9 percent in 2021, reaching about 278 million international patent filings and setting a new record, but still down from the 3.6 percent growth in 2020, as detailed in WIPO's *Patent Cooperation Treaty Yearly Review*.[11] There was a marked slowdown in growth from China – the largest origin of international patent filings. However, this was unrelated to the crisis; rather, the Chinese Government phased out patent filing subsidies during the course of 2021.[12]

Following the 2020 trend, health-related technologies continued to register the fastest growth among all fields of technology.[13]

Figure 5 Corporate R&D expenditure, selected top R&D spenders worldwide, annual R&D expenditure, 2020 vs 2021



Source: WIPO, based on BvD Orbis database.

Interestingly, trademarks – a good proxy for the introduction of new goods and services in the market as well as the creation of new companies – saw spectacular growth in 2021, by close to 15 percent. In the three most recent crises, there was a sharp initial decline in international trademark applications. However, the COVID-19 crisis stands out in showing the shallowest decline, followed by an extraordinary boom in applications about a year into the crisis. Analysis of keywords listed in the description of trademark applications suggests that the fast growth was driven, in particular, by new goods and services that rely on digital business models, fostered by the pandemic's disruptions and the accelerated adoption of digital technologies.[14]

Venture capital

Financing innovation in times of economic crisis typically becomes more challenging during economic recessions.[15] In past economic crises – especially those resulting from imbalances in the financial system – VC deals and investment values turned sharply negative at the outset of a crisis, only to recover with an improving business cycle.

However, this crisis was different for VC too. Within a few months, a historic boom in VC deals had begun. The number of VC deals grew by 8.5 percent in 2020 (deal values by 15.3 percent), exceeding (on par with) the indicator's 10-year average growth rate of 3.6 and 15.6 percent respectively.

This trend continued into 2021. The number of VC deals grew by a further 46 percent in 2021 – reaching almost 20,000 deals worldwide, with around 4,800 deals sealed per quarter – and the deal values increased by 126 percent – to total USD 618 billion (see Figure 6), also exceeding the indicator's 10-year average growth rate of 7.3 and 23.6 percent respectively.

In 2021, VC deals showed strong growth in all regions of the world. Latin America and the Caribbean (+98.7 percent) and Africa (+75.4 percent) witnessed the strongest growth, albeit from a low starting point, both reaching around 300 deals in 2021. The last time that the Asia Pacific region (+67.3 percent), Europe (+53.4 percent) and Northern America (+28.3 percent) experienced growth as high as that recorded in 2021 was over 15 years ago.

For every dollar invested in a VC deal in 2021, half (51 cents) went to North American companies, 32 cents to Asia Pacific, 14 cents to Europe and 3 cents to Latin America and the Caribbean. In 2021, VC investments more than quadrupled in Africa and Latin America to USD 3 billion and USD 16 billion, respectively. Europe, the Asia Pacific region and Northern America also received more than double the amount of the previous year.

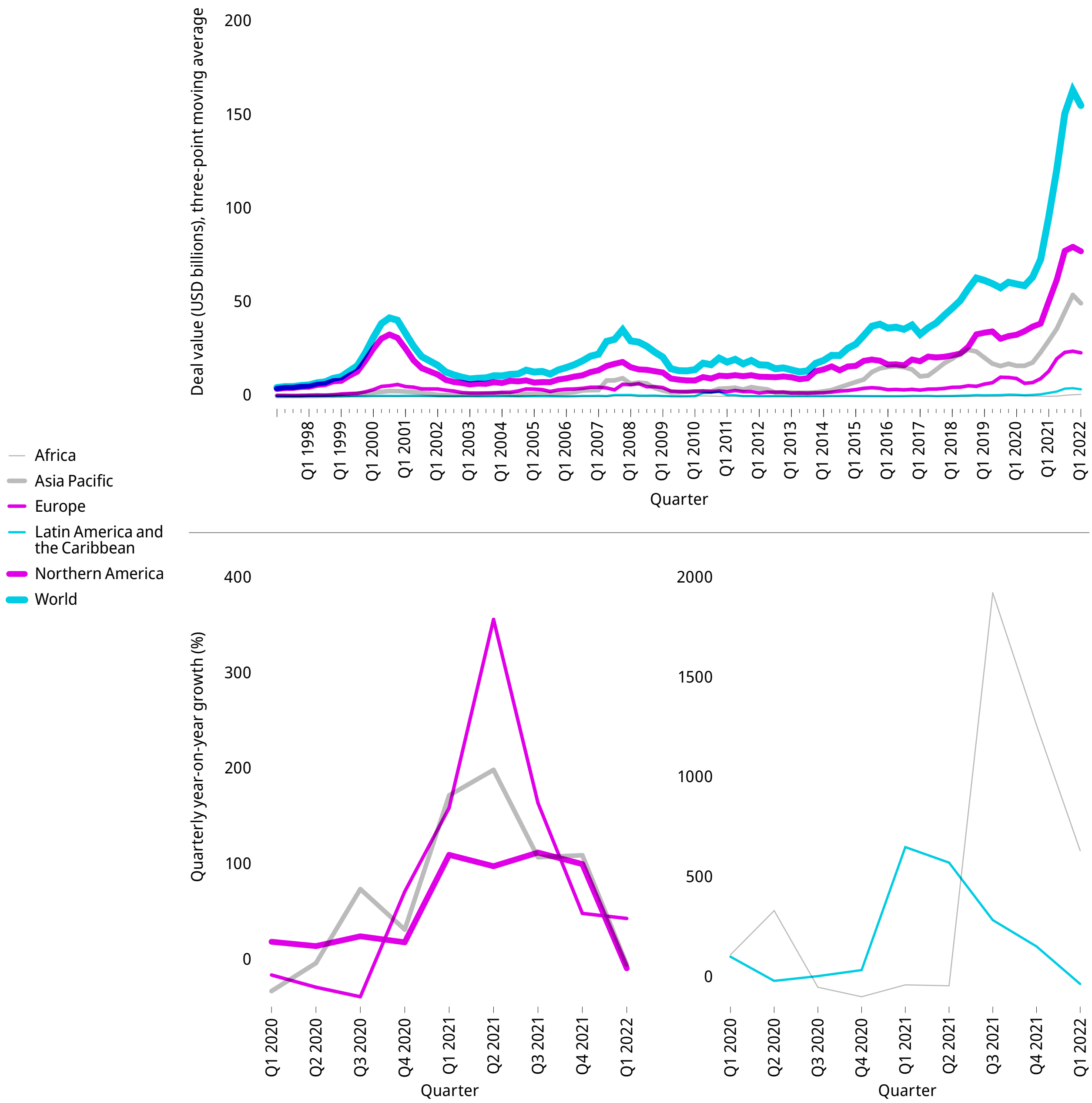
Financial services dominate Latin America's startup scene and this is clearly reflected in the top 10 most valued VC deals in the region (which received USD 4 billion of the USD 15.7 billion). Five of the top 10 deals were sealed by fintech companies, such as Nubank, which now has more customers than any other standalone digital bank in the world. Another four were startups in online platforms. Kavak (Mexico's first unicorn), for example, provides digital solutions to the often hazardous experience of buying a used car and Brazil-based Quinto Andar is making it simpler to rent a flat by eliminating the need for brokers and offering its own insurance.[16]

Seven of the top 10 most valued VC deals in Africa were in financial services. South Africa and Egypt both had three deals each in the top 10. WIOCC, a Mauritius-based company, received USD 200 million of venture capital that will be used to enhance Africa's digital infrastructure by expanding connectivity and open access data centers. South African Yoco Technologies received USD 83 million in 2021 and offers simple card machines and online payment tools to avoid the difficulties that entrepreneurs often face in accessing payment tools.

The outlook at the start of 2022 was much more somber. In contrast to the impressive quarterly year-on-year growth seen in VC deals between Q1 2020 and Q1 2021 (+47.4 percent), growth in the first quarter of 2022 was notably less strong; +13.2 percent on Q1 2021. Nevertheless, Africa still saw the strongest growth in Q1 2022 (+43.5 percent, relative to Q1 2021).

In addition, more anecdotal evidence in the second quarter of 2022 – also triggered by tightening monetary policies with a knock-on effect on risk capital – indicates a sharp deceleration or decline in VC deals in the months ahead.

Figure 6 Value of VC deals by region, three-point moving average, 1997–2022 (top), and growth in value of VC deals, by region, 2020–2022 (bottom)



Source: WIPO, based on data by Refinitiv Eikon (private equity screener), accessed May 27, 2022.
Notes: Africa and Latin America and the Caribbean are subject to high volatility due to low volume numbers.

Technological progress

The indicators of *technological progress* in the fields of semiconductor speeds, electric battery prices, the cost of renewable energy and drug approvals show a significant slowdown from long-term trends, and even a decline in the case of drug approvals.

The spurts in science and innovation investments described earlier in the period 2020 to 2022 are badly needed to revive technological progress, which – according to the indicators included in the Global Innovation Tracker – is currently slowing down, although sometimes from high initial levels. Moore's law no longer applies and both electric battery prices and the cost of solar photovoltaic energy generation have declined less than the historic trends might have suggested. The exception is the cost of wind power, which has declined faster in 2020 than the longer-term trend of the past 10 years.

Microchip transistor count

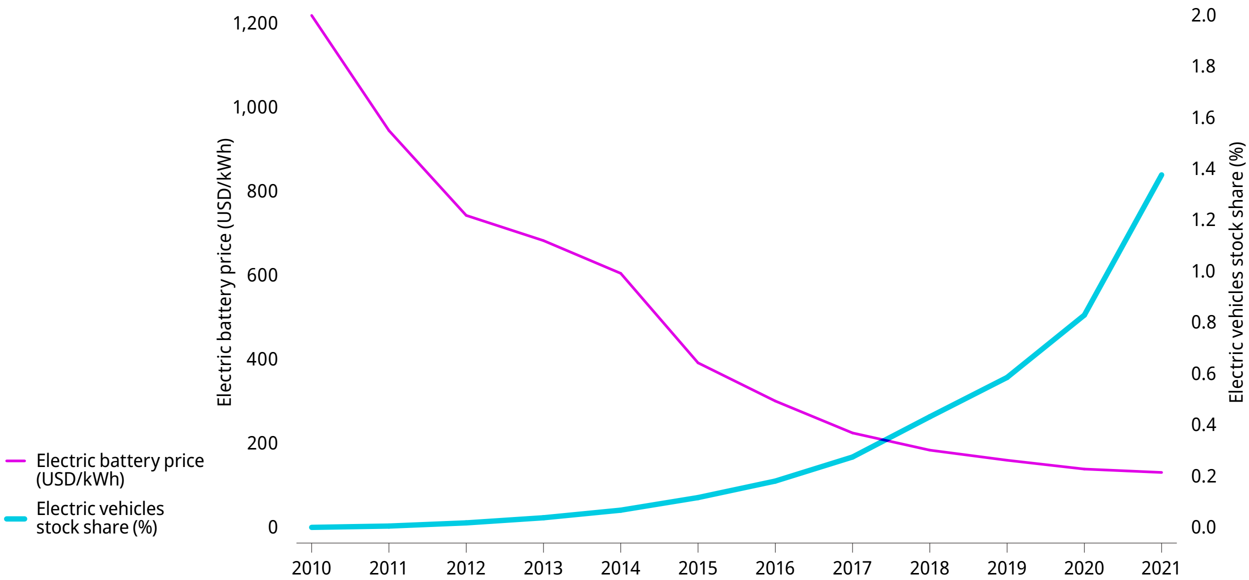
Moore's law famously predicted that the speed and capability of our personal computers (measured by the number of transistors on microchips) would double every two years. This prediction has proved roughly true since the 1970s but does it still hold? Over the past 10 years, technological progress has slowed somewhat and the latest 2019 to 2021 trend suggests even slower progress: the transistor count of our personal computers increased by 21.4 percent over this period, which implies a count that is doubling only every four years. While short-term transistor count data are volatile, it seems likely that advances in microchip technology are no longer occurring at the pace implied by Moore's law. Other factors, such as more efficient programming languages, can continue to increase capacity, but these may start to selectively target specific problems and business opportunities, and not have the same effect of "lifting all boats" as the cumulative potency of Moore's law did.[17]

Electric battery price

Electric vehicles (EVs) are generally still more expensive than petrol and diesel vehicles due to their use of expensive lithium-ion batteries. Thankfully, the price decline for electric batteries has typically been by double-digit percentages over the past decade (a 17.9 percent decline on average per year, see Dashboard and Figure 7), supporting the continued electrification of transport and other sectors. Over the past decade, battery prices have fallen from USD 946 per kilowatt-hour (kWh) to just USD 132 per kWh in 2021. However, the electric battery price decline has slowed down from a 13 percent reduction in 2020 to a 5.7 percent reduction in 2021. This was due to a rise in the cost of raw materials used in the cathode – lithium, cobalt and nickel – putting such pressure on the industry that the Chinese battery manufacturer BYD announced a 20 percent increase in its battery prices in November 2021.[18] Despite the cost increase, the current volatility of gasoline and diesel prices have kept up demand for EVs thus far in 2022.[19]

Worse still, the effects of these major price increases for lithium will only be felt by many car manufacturers in the first quarter of 2022, as contracts for battery orders are increasingly linked to three-month trailing commodity prices. The realization may be dawning that electric battery prices may not necessarily continue to fall as rapidly each year in the near future. This will have impacts beyond just the EV market as it also affects the electrification of other transport means (planes, buses, and so on) as well as smartphones and computers.

Figure 7 Electric battery price and electric vehicle stock share, 2010–2021



Sources: WIPO, based on *2021 Lithium-Ion Battery Price Survey*, BloombergNEF and *Global EV Outlook 2021*, International Energy Agency.

Costs of renewable energy

Even though technological progress continues to drive down the costs of renewable energy, in the case of solar photovoltaic energy, costs fell by only 7 percent between 2019 and 2020, the lowest drop in the past decade. This decline is far below the 10-year average rate of decline of 17.3 percent per year, indicating a declining cost reduction potential. In the case of wind energy, the opposite holds: costs fell by 12.5 percent between 2019 and 2020, a decrease that is higher than the 10-year average rate of 7.5 percent.

Renewable energy sources are about to go through testing times, in an environment of new energy security worries. Pressure to secure greater energy independence has led to new investment in oil and gas – and the reaffirmation of nuclear energy – but further progress in renewables will be key to sustaining price declines and innovation in the field of renewable energies in the future.

Drug approvals
Drug approvals are an imperfect proxy for technological progress in healthcare in the GII Global Innovation Tracker and the data used are not readily available internationally.

The United States Food and Drug Administration (FDA) approved 50 new drugs and biologics products in 2021. This number is slightly below the 53 approvals recorded in 2020 and 59 approvals in 2018. However, the long-term trend is still positive, with average annual growth of 5.2 percent since 2011. Note that these figures do not include vaccines, which fall under a different FDA approval track.[20] Given the contribution made by the COVID-19 vaccines to public health, they therefore understate the recent technological health-related progress achieved.

Much has been written and said about the potential of new platform technologies – such as the mRNA and CRISPR tools – to foster the development of new vaccines and treatments for both old and new diseases, and possibly to trigger a new health-related innovation wave (see the Special theme section).[21] However, even if these technologies can accelerate R&D cycles in the future, it will still take years for new drugs and treatments to receive regulatory approval.

Technology adoption

***Technology adoption* is progressing, with positive growth rates across technologies measured by the Global Innovation Tracker, and in particular for electric vehicles. However, penetration rates are still medium to low, with the exception of mobile broadband, which reaches the vast majority of the global population.**

The real impact of advances in science and technological progress is heavily dependent on the extent to which society accepts, integrates and adopts new technology. However, as set out below and in this year's Special theme section, it is not unusual for inventions deployed in the marketplace as innovations to take decades before they are widely adopted; and most never make it. Even if all our technology adoption indicators demonstrate healthy and even strong year-on-year growth, they are sometimes marginally slower than the long-term trend. For broadband, this is admittedly due to the already high penetration rates, while the growth rate of EVs is based on much lower absolute levels. Achieving higher levels of penetration is a challenge for all technologies, the exception being mobile broadband, which already has impressive world penetration rates.

Broadband penetration
Both fixed and (active) mobile broadband subscriptions showed positive growth in 2021 compared to 2020; +5.7 and +7.6 percent, respectively, with both growth rates below their 10-year averages. As of today, 17 out of every 100 inhabitants are connected to fixed broadband, compared to 9 out of every 100 inhabitants in 2011. Even though year-on-year mobile broadband growth picked up pace again in 2021 (+7.6 percent), adoption was surprisingly sluggish during the three years prior to that, hinting at saturation, admittedly at high levels of penetration. In turn, despite double-digit growth in many low-income economies, fixed broadband remains accessible only to very few, with a penetration rate of just 1.4 subscriptions per 100 inhabitants.[22] This means that a non-negligible share of the world's population still does not have internet access, and certainly not the fast, more stable fixed broadband necessary for those applications and activities for which mobile broadband speeds are not sufficient. Overall, however, the speed and efficacy of internet and broadband deployment around the world is one of the most successful in the history of all technologies.

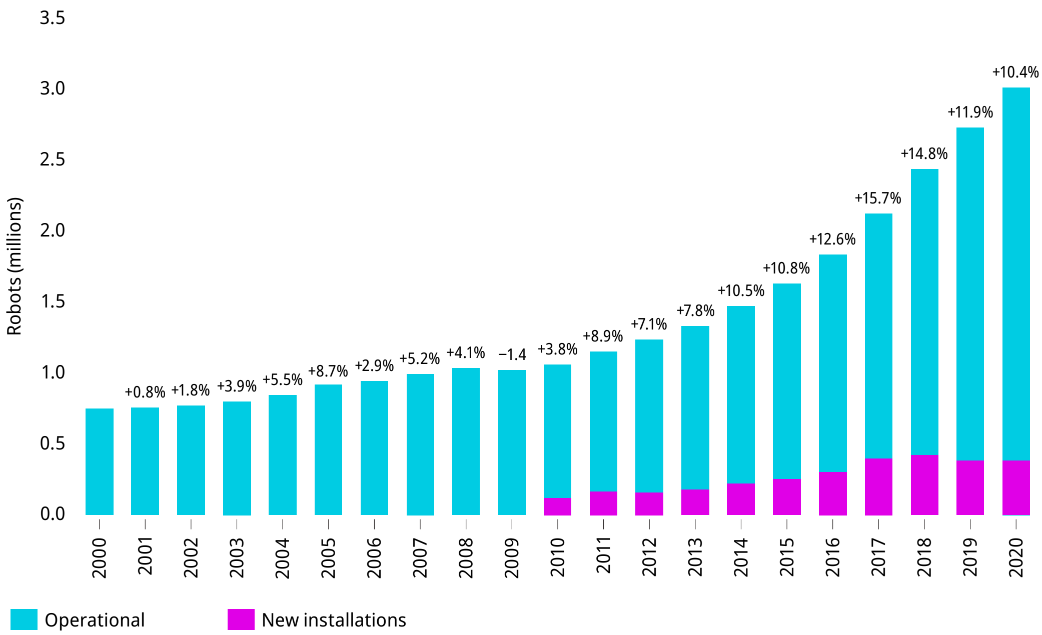
Robots and automatization
The stock of industrial robots deployed worldwide reached the 3 million mark in 2020 (see Figure 8), up from 1 million in 2010 and 0.8 million in 2000. This represents a 10.4 percent increase compared to 2019 and is similar to the average annual growth rate of 11 percent since 2010. The five major markets for industrial robots are China (accounting for 44 percent of new installations), Japan (10 percent), the Republic of Korea (8 percent), the United States (8 percent) and Germany

(6 percent), and they all experienced strong growth. Together, these countries account for three-quarters of new robot installations worldwide.

Since there is no obvious saturation level, it is hard to tell how widely deployed robots are, but experts point to significant deployment potential ahead.[23]

Today, overall automatization is still relatively low in less technology-driven sectors and in middle- and low-income economies (with the exception of China). This holds true not only for physical automatization via physical robots, but also for automatization via soft robots, such as artificial intelligence (AI).

Figure 8 Stock of industrial robots and year-on-year growth rate (%), 2000–2020



Source: WIPO, based on data from the World Robotics Industrial Robots and Service Robots Database of the International Federation of Robotics.

Notes: The stock is computed on the assumption of a 12-year service life. Installations are based on the shipment data of robot producers. Cyan + purple represent the total number of operational robots. Purple represents the share of robots that were newly installed in a given year.

Electric vehicles

Over 16.5 million electric cars were on the world's roads by the end of 2021, representing a tripling of the number in just three years.

Europe overtook China as the world's largest EV market for the first time in 2020, in terms of the absolute number of car registrations – 1.4 million and 1.2 million, respectively. However, China considerably outpaced Europe once again in 2021; more electric cars were sold in China (3.3 million) than anywhere else in the world combined.

While overall car sales experienced a pandemic-related worldwide downturn in 2020, (new) electric car registrations saw growth of 41 percent in 2020 and registrations continued to rise, increasing by 120 percent to 6.6 million in 2021. This was largely encouraged by the COVID-19 stimulus measures with respect to EVs introduced by many European governments, as well as policy targets that limit the average CO_2 emissions per kilometer driven for new cars.[24] Additional factors contributing to EVs' resilience are higher fuel prices, the growing variety of EV models, their ability to cover longer distances and the continuing (though now slowing) decline in battery prices (see Dashboard).

Despite the rapid growth of worldwide EV stock over the past decade (+74 percent), this still represents a very small fraction of all cars (1.4 percent). The Nordic countries lead on EV penetration – Norway (25.3 percent), Iceland (9.9 percent), Sweden (6 percent) and Denmark (5.2 percent) – while EV penetration is still below 0.1 percent in Brazil, Chile, India and Mexico.

Socioeconomic impact

Largely due to the short-term influences of the COVID-19 pandemic, the *socioeconomic impact* of innovation seems to be at a low point, with labor productivity and life expectancy experiencing a significant slowdown if not coming to a standstill and, in the case of carbon emissions, failing to show ongoing reductions in pollution.

Historically, technological progress has had a positive impact on people's daily lives, in terms of increased living standards, better health outcomes and sustained economic growth. What good are science and innovation investments, innovation progress or technology adoption if no impact is felt in economic terms (i.e., productivity), well-being measured in gross domestic product (GDP) per capita increases or broader welfare benefits, such as a healthy, long-living population or a healthy planet.

In 2022, this is the most pessimistic part of the Global Innovation Tracker, mirroring the findings of the GII 2022 Special theme section. Broadly, 2020 and/or 2021 and the previous years saw stagnation in the chosen track metrics: labor productivity (the prime metric for understanding the impact of technology on the efficacy of our production systems), carbon dioxide emissions (one measure of how well we are managing to avert the looming climate catastrophe) and life expectancy (a measure of how the health and life of people is improving on the ground).

Labor productivity

Economists and policymakers around the world have been worrying for decades about low productivity growth and how to turn this around using innovation – the theme of the GII 2022 "What is the future of innovation-driven growth?".

Interestingly, the year 2020 saw a rapid increase in global labor productivity growth (4.5 percent) – particularly notable in contrast to the previous stagnation of productivity experienced since the 1970s in most advanced nations.

Hopes for a productivity revival were dashed again when output per hour worked stagnated in 2021 (0 percent growth, which is the lowest growth seen in at least the last 15 years in comparison to the 2.3 percent average annual growth that occurred over the past decade). As containment measures were relaxed, employment returned to pre-pandemic patterns and reallocation effects dampened aggregate productivity growth (read the full story in the Special theme section).[25] Forecasts for 2022 expect continued stagnation, also due to increased input costs caused by factors such as energy and supply chain disruptions resulting from the Russian Federation–Ukraine conflict (see Figure 19 in the Special theme section).

Life expectancy

Life expectancy has seen a considerable increase over the long term, rising to 72.7 years in 2020, up from 52.6 years in 1960.[26] Scientific advances have promoted effective treatments against a wide range of diseases. However, in 2020 life expectancy was marginally down from 2019 figures (declining by 0.02 percent), representing the first fall in life expectancy in modern history. This, probably temporary, decline reflects the increase in mortality due to the onset of the COVID-19 pandemic, but there is also a more systemic, gradual slowdown in the average annual life expectancy growth rate over the past six decades: 1960s – annual average growth rate of 1.1 percent; 1970s – 0.7 percent; 1980s – 0.4 percent; 1990s – 0.3 percent; 2000s – 0.4 percent; and 2010s – 0.3 percent. High-income countries – which tend to have older populations – experienced the largest decline (−0.8 percent) but still have the longest life expectancy at 80.2 years. Other income groups all experienced slight growth in 2020: upper middle-income (+0.05 percent, 76 years), lower middle-income (+0.3 percent, 69.3 years) and low-income (+0.5 percent, 64.1 years) – although their short-term growth has been below their long-terms growth trends, at least since 2014.

Carbon dioxide emissions

Similar to life expectancy, carbon dioxide (CO_2) emissions saw a deviation from the long-term trend. They declined by 5.2 percent in 2020, as governments' containment measures to combat the pandemic slowed the social and economic activities responsible for these emissions. Those activities rebounded in 2021 and CO_2 emissions are estimated to have risen again by 4.9 percent in 2021, casting doubt on the proposition that 2019 could have been a tipping point in global fossil-fuel emissions.[27] Comparing the first five months of 2022 to those of 2021, the increase in CO_2 emissions again appears more modest, with 1.1 percent growth, but data are subject to updates and should therefore be carefully monitored.[28]

There is much uncertainty concerning how emissions will evolve in the coming years. The long-term decline of fossil energy may only begin once non-fossil energy sources can supply the entirety of new energy demand. While technological progress (observed as reductions in the cost of renewable energy) and the recent increase in the price of fossil fuels will, in principle, favor investments in renewable energy, certain economies seeking energy independence are planning to increase their reliance on fossil fuels, at least temporarily.

Conclusion

The GII's Global Innovation Tracker provides a data-driven perspective on the latest innovation trends. It offers the following insights:

- Overall, investments in science and innovation have been remarkably resilient in the face of the economic downturn.
- Nonetheless, the global pandemic has left its mark on the global innovation landscape. Until science and innovation investment data for a broader set of firms and countries are available, it is impossible to assess whether or not the pandemic has ultimately negatively impacted those firms and economies which are not already the leading R&D superfirms and the leading innovation nations.
- Technological progress at the frontier and technology adoption hold substantial promise. However, the data also show that, certain advances and top performances aside (such as mobile broadband penetration), some progress is faltering – for example, Moore's law no longer holding true and penetration rates remaining relatively low.
- The socioeconomic impact of innovation is currently, judging by the metrics employed here, at a historic low, also, in part, reflecting the influence of the COVID-19 pandemic. It will be important to follow how its impact will evolve as the world transitions out of this crisis.

Notes

1 Relative to the first edition of the Global Innovation Tracker in 2021, the theme of *technology adoption* – comprising broadband, robots and electrical vehicle penetration – has been added, as has a proxy for electric battery price to the *technological progress* section.

2 IMF, 2022.

3 Government R&D budget indicators for the OECD area present the amounts that governments agree to allocate to R&D as part of their budgetary processes, rather than actual expenditure reported by R&D performers.

4 Using the top spenders compiled in the European Commission's 2021 EU Industrial R&D Investment Scoreboard as a starting point and WIPO's own calculations facilitated by the Bureau van Dijk (BvD) Orbis database. See Grassano *et al.* (2021) for the scoreboard information.

5 See also the OECD Short-term Financial Tracker of Business R&D (SwiFTBeRD), which shows positive real annual growth in the order of 7 percent in 2021.

6 See the Global Innovation Tracker 2021: www.wipo.int/edocs/pubdocs/en/wipo_pub_2000-section2.pdf.

7 WIPO, 2022; Fink *et al.,* 2022.

8 WIPO, 2010: WIPO, 2011.

9 "Innovative Activity Overcomes Pandemic Disruption – WIPO's Global Intellectual Property Filing Services Reach Record Levels", Geneva, February 10, 2022, PR/2022/886, www.wipo.int/pressroom/en/articles/2022/article_0002.html.

10 WIPO, 2022.

11 WIPO, 2021; WIPO, 2022.

12 For further details see https://english.cnipa.gov.cn/art/2021/5/20/art_1340_159520.html.

13 See the Global Innovation Tracker 2021: www.wipo.int/edocs/pubdocs/en/wipo_pub_2000-section2.pdf.

14 Fink *et al.,* 2022.

15 See the GII 2020 Special theme: www.wipo.int/edocs/pubdocs/en/wipo_pub_gii_2020-chapter3.pdf.

16 *Financial Times*, 2021.

17 Rotman, 2020.

18 See www.bloomberg.com/news/articles/2021-11-30/battery-price-declines-slow-down-in-latest-pricing-survey.

19 See www.reuters.com/business/autos-transportation/soaring-battery-costs-fail-cool-electric-vehicle-sales-2022-04-19.

20 Two COVID-19 vaccines have been approved by the FDA so far: Comirnaty, developed by BioNTech and Pfizer, and Spikevax, developed by Moderna.

21 See also www.wipo.int/edocs/pubdocs/en/wipo_pub_gii_2019-chapter1b.pdf.

22 ITU, 2021.

23 Müller, 2021.

24 See www.iea.org/reports/global-ev-outlook-2021/trends-and-developments-in-electric-vehicle-markets.

25 Other measures of productivity, notably total factor productivity, show similar long-term declines, especially in developed economies (Moss *et al.,* 2020).

26 Dutta *et al.,* 2019.

27 Davis *et al.,* 2022.

28 Carbon Monitor, https://carbonmonitor.org, accessed June 1, 2022.

Data notes

Scientific publications captures the number of peer-reviewed articles published in the Social Sciences Citation Index (SSCI) and Science Citation Index Expanded (SCIE). Source: Web of Science (Clarivate), https://apps.webofknowledge.com.

R&D expenditures captures R&D expenditures worldwide in PPP-adjusted constant 2015 prices. The 2020 values were calculated using available real data of gross expenditure on R&D (GERD) and business enterprise expenditure on R&D (BERD) at the country level from the UNESCO Institute for Statistics (UIS) online database, the OECD's Main Science and Technology Indicators (MSTI) database (March 2022 update), Eurostat and the Ibero-American and Inter-American Network of Science and Technology Indicators (RICYT). For those countries for which data were not available for 2020, the 2020 data were estimated using the last observation carried forward (LOCF) method. The R&D section also includes data on government budget allocations for R&D for 2019, 2020 and 2021 sourced from the Joint OECD–Eurostat data collection on resources devoted to R&D, July 2022, with figures in current US dollars. Data for the top global R&D spenders, in turn, are derived using the top spenders compiled in the European Commission's 2021 EU Industrial R&D Investment Scoreboard as a starting point and WIPO calculations facilitated by the Bureau van Dijk (BvD) Orbis database, with all figures in current US dollars.

International patent filings refers to the total number of patent applications filed through the WIPO-administered Patent Cooperation Treaty. Source: WIPO IP Statistics Data Center, https://www3.wipo.int/ipstats.

Venture capital. VC deals refers to the absolute number of VC deals received by companies located in the region. VC value refers to the total amount of current US dollars invested – via venture capital – into companies located in the region. Source: Refinitiv Eikon data on private equity and venture capital, www.refinitiv.com/en/products/eikon-trading-software/private-equity-data.

Microchip transistor count refers to the number of transistors on the most advanced commercially available microchips in a given year. Source: Karl Rupp, https://github.com/karlrupp/microprocessor-trend-data.

Electric battery price refers to the average lithium-ion battery price (in 2021 US dollars, including the cell, module and pack), weighted by power capacity (MWh), across all sectors. Source: *2021 Lithium-Ion Battery Price Survey*, BloombergNEF (BNEF). BNEF is a strategic research provider covering global commodity markets and the disruptive technologies driving the transition to a low-carbon economy. https://about.bnef.com.

Costs of renewable energy captures the global weighted average levelized cost of electricity generation of solar photovoltaics and onshore wind. Source: International Renewable Energy Agency (IRENA), www.irena.org/publications/2021/Jun/Renewable-Power-Costs-in-2020.

Drug approvals refers to the number of new drugs approved by the US Federal Drug Administration (FDA). The data include both small molecule drugs and biologics. Source: FDA, www.fda.gov/media/135307/download.

Broadband penetration is equivalent to the number of fixed and (active) mobile broadband subscriptions, respectively, per 100 inhabitants. Source: International Telecommunication Union (ITU) World Telecommunication/ICT Indicators database, www.itu.int/en/ITU-D/Statistics/Pages/facts.

Robots measures the number of robots currently deployed in industrial automation applications (also known as the operational stock of industrial robots). The stock is calculated assuming an average service life of 12 years with immediate withdrawal from service at the end of this period. Source: International Federation of Robotics (IFR), https://ifr.org/ifr-press-releases/news/robot-sales-rise-again.

Electric vehicles stock share is the percentage of passenger cars worldwide that are battery electric vehicles (BEVs) or plug-in hybrid electric vehicles (PHEVs). Source: International Energy Agency (IEA), www.iea.org/articles/global-ev-data-explorer.

Labor productivity refers to the world total of output per hour worked, as estimated by The Conference Board. Source: The Conference Board Total Economy Database™, https://conference-board.org/data/economydatabase.

Life expectancy refers to the number of years a newborn infant would live if prevailing patterns of mortality at the time of its birth were to stay the same throughout its life. Source: World Development Indicators, https://databank.worldbank.org/source/world-development-indicators.

Carbon dioxide emissions refers to fossil emissions, excluding carbonation, for the world, measured in billion tons of CO_2 per year. Source: Global Carbon Project (2021). Supplemental data of Global Carbon Budget 2021 (Version 1.0), https://doi.org/10.18160/GCP-2021.

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