Global Innovation Index 2022

What is the future of innovation-driven growth?

WIPO

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Global Innovation Index 2022

What is the future of innovation-driven growth?

15th Edition

Soumitra Dutta, Bruno Lanvin,
Lorena Rivera León and Sacha Wunsch-Vincent

Editors

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Foreword

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Daren Tang, Director General, World Intellectual Property Organization (WIPO)

Welcome to the 15th edition of WIPO's flagship *Global Innovation Index* (GII), where we track the current state of innovation globally and rank the innovative performance of 132 countries.

This year's GII finds the innovative sectors of the world economy at a crossroads. On the one hand, science and innovation investments continued to surge in 2021, performing strongly even at the height of a once in a century pandemic. International patent filings, R&D expenditure, scientific publications and other key innovation metrics also all showed continued growth.

Take the trend in venture capital (VC) deals. Typically, the pool of capital available for financing innovation shrinks during periods of economic turbulence, with VC investment declining in line with the overall business cycle. However, the current crisis has instead seen a historic boom in VC activity, with the number of deals increasing by almost 50 per cent last year.

On the other hand, even as the pandemic recedes, storm clouds remain overhead, with increasing supply-chain, energy, trade and geopolitical stresses.

In such a world, understanding the state of innovation is even more critical than ever, and this is why the theme of this year's GII is the future of innovation-driven growth. With contributions from experts and business leaders from around the world, we explore the trajectory of key innovation indicators, including the rate of technological progress, the underlying technology adoption and the socioeconomic impact of innovation. Two innovation waves in particular are identified as having the greatest potential to improve productivity and change lives for the better – the Digital Age and Deep Science.

Supporting countries at all stages of development in strengthening their innovation ecosystem is a key objective of the GII. More than a reference guide, the GII has established itself as a powerful tool for the construction and development of pro-innovation policies, with countries working with us to create similar indices at the sub-national level.

To help quantify its reach and impact, last year we gathered information from Member States on how they use the Index. Of the 110 responding countries, more than 75 use the GII either to improve their innovation ecosystem, strengthen innovation metrics, or as a specific reference in economic policymaking.

During a time of continued economic volatility, WIPO stands ready support all our Member States in harnessing innovation for the benefit of economies and societies the world over, creating jobs, attracting investments and boosting growth. I sincerely hope that this year's GII will help each and every country to find the best levers to make this happen.

Acknowledgments

The *Global Innovation Index 2022* was prepared under the general direction of Daren Tang, Director General, in WIPO's IP and Innovation Ecosystems Sector led by Marco Alemán, Assistant Director General, and in the Department of Economics and Data Analytics led by Carsten Fink, Chief Economist.

The report and rankings are produced by a core team managed by Sacha Wunsch-Vincent, Head of Section, comprising Vanessa Behrens, Project Manager, Jack Gregory, Innovation Data Analyst, and Lorena Rivera León, Economist, from the WIPO Composite Indicator Research Section responsible for the GII, and the following consultants: William Becker, Abdellah Bouhamidi, Rafael Escalona Reynoso and Valentin Todorov – all in a personal capacity.

Soumitra Dutta (Oxford University and Portulans Institute), Bruno Lanvin (Institut Européen d'Administration des Affaires, INSEAD, International Institute for Management Development, IMD and Portulans Institute), Lorena Rivera León (WIPO) and Sacha Wunsch-Vincent (WIPO) serve as co-editors of the GII.

For significant contributions to the special GII 2022 theme on "What is the future of innovation-driven growth?", we thank Klaas de Vries (Conference Board), as well as Bart van Ark (The Productivity Institute and University of Manchester), who acted as reviewer, Charlotte Beauchamp, who acted as editor and Francesca Guadagno for inputs. Furthermore, appreciation goes to all the authors of the eight Expert Contributions on this year's theme (published online) for their insightful analysis, national context and industry perspectives.

The following WIPO colleagues provided substantive inputs to the GII elaboration or dissemination: Hao Zhou, Director of Statistics, and Kyle Bergquist, Data Analyst, from the Statistics and Data Analytics Division, as well as colleagues from the External Relations Division, the Information and Digital Outreach Division, the IP and Innovation Ecosystems Sector, the Language Division, the News and Media Division, the Printing Plant, the Regional and National Development Sector, the WIPO Office in New York, and WIPO's External Offices.

A special thank you goes to our partners at the Portulans Institute, in particular, Rafael Escalona Reynoso, Mariam Chaduneli and Sylvie Antal for their contributions. We also thank the GII's Advisory Board, Corporate Network, Academic Network and the GII Data Collaborators for their participation, as well as to the Competence Centre on Composite Indicators and Scoreboards (COIN) team from the European Commission's Joint Research Centre – led my Michaela Saisana – that conducted the statistical audit. The report was edited by Richard Cook and Andy Platts at Book Now Ltd. Gratitude is also due to the creative production of the GII website carried out by StratAgile PTE Ltd.

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Advisory Board

In 2011, an Advisory Board was established to advise on the strategic direction of the Global Innovation Index (GII), to help more broadly in emphasizing the important role innovation plays in economic and social development, and to assist in sharing the GII results as they relate to each of the world's economies and regions. The Advisory Board is a select group of international policymakers, thought-leaders and corporate executives. Members are drawn from diverse geographical and institutional backgrounds and participate in a personal capacity. We extend our gratitude to all Advisory Board members for their continued support and collaboration.

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Houlin Zhao
Secretary-General, International Telecommunication Union (ITU)

The GII Partners

Preface

Soumitra Dutta and **Bruno Lanvin**
Co-editors of the *Global Innovation Index*
Co-founders of the Portulans Institute

For a second year, the *Global Innovation Index* (GII) is published by WIPO in partnership with the Portulans Institute, with the support of our Corporate Network partners, namely, the Brazilian National Confederation of Industry (CNI, Brazil), the Confederation of Indian Industry (CII, India), Ecopetrol (Colombia) and the Turkish Exporters Assembly (TİM, Türkiye). We at Portulans are very grateful to all our partners for their continued support and enthusiasm for the GII. We owe a great debt of gratitude to WIPO and its dedicated team of professionals under the leadership of Director General Daren Tang and Assistant Director General Marco Alemán. We further extend our appreciation to the Academic Network (to which we welcome the University of Johannesburg, the University of Oxford and VinUniversity) for its invaluable contribution to our work and to continuing research around innovation and the GII.

This year has, so far, been marked by the many tensions that have arisen around the world. Whereas many of us were expecting growth and trade to pick up rapidly in a post-COVID environment, geopolitical tensions have taken a new turn with the Russian Federation–Ukraine conflict and inflationary pressures are also making a global comeback. The risk of a splintered world economy has grown. In particular, poorer economies risk hunger on a massive scale, while growing inequalities and poverty threaten to put the world back several decades.

In such an uncertain context, innovation has a critical role to play. More than ever, innovation must be the target of strong, counter-cyclical policies. Productivity gains continue to justify spending on innovation. But at a time when financial resources are stretched – and competition for these resources stronger – it is even more important in 2022 to make explicit the links between innovation and productivity.

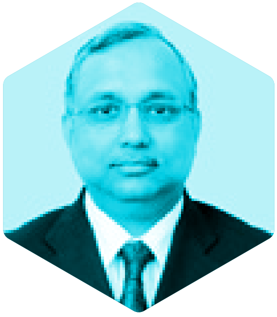
As last year's edition of the GII underlined, the COVID-19 pandemic has made fragile the innovation ecosystems of a great many emerging and poorer economies. Hence it is vitally important to consider how such systems can be strengthened and brought closer to local needs, as well as national interests, as a new type of globalization confronts the world.

In this era of growing uncertainties, it is our strong belief that the GII has a significant role to play by pursuing its goal of providing the factual and quantified evidence to allow private and public stakeholders to make the best decisions they can, and in so doing adopt more efficient strategies.

Corporate Network

Chandrajit Banerjee, Director General, Confederation of Indian Industry (CII)

Future innovation – The new economic catapult for productivity and growth



As India celebrates its 75th year of Independence on a strong foundation for productivity and growth, an acceleration in scientific and technical innovation is driving rapid economic progress throughout the country.

Today, India is experiencing significant transformations, from space technology and smart cities to health care and telecommunications, all driven by innovative solutions. India's Chandrayaan-2 Moon orbit, digital identity technologies (Aadhar), universal health care and the indigenous vaccine Covaxin®, are just several prominent examples of the country's current innovation prowess across various sectors.

Using frontier technologies, Indian companies are making significant leaps in innovation. In so doing, they are making their contribution to the country's socioeconomic transformation. Additionally, a startup culture has taken root across the country, positioning India as the third biggest startup economy in the world.

WIPO's *Global Innovation Index* (GII) captures all these developments, showing where India continues to improve its innovation performance and encouraging further expansion of its knowledge inputs and outputs. This year's Special theme focusing on "What is the future of innovation-driven growth?" examines the role and impact of digital innovations in enhancing productivity throughout the country.

The Confederation of Indian Industry (CII) is working in close partnership with the Indian Government and other stakeholders in inspiring Indian industry to recognize and embrace innovation. As we strive to raise enterprises to the next level of technological innovation, we are prioritizing capacity building, academic collaboration and international cooperation in sharing best practice.

As a founding knowledge partner of GII, CII is proud to be an integral part of India's journey toward an innovation-driven knowledge economy. Over the years, the GII has evolved into an invaluable benchmarking tool encouraging nations to leverage innovation for economic prosperity and social good.

I congratulate the GII team for the 2022 edition of the report. This continues to provide a useful guide for exploring the multi-dimensional layers of innovation and productivity across the globe.

Robson Braga de Andrade, President, Brazilian National Confederation of Industry (CNI)

Innovation and productivity vectors – Human resources, digital transformation and sustainability

Innovation is crucial to increasing productivity in emerging economies with recent growth-related difficulties, such as Brazil.

Coordinated by the Brazilian National Confederation of Industry (CNI), the Entrepreneurial Mobilization for Innovation (MEI) is a group of business leaders fostering an innovative culture by proposing policies aimed at increasing funding and modernizing the regulatory framework for science, technology and innovation (STI) in Brazil. In this regard, three noteworthy MEI working groups cover: human resources, digital transformation and sustainability.

Economic expansion is, to a large extent, the result of labor productivity gains. Between 2011 and 2019, GDP per employed worker increased in China (4.5 percent), the European Union (1.1 percent) and the United States of America (0.6 percent). During the same period, Brazil recorded zero growth. Good education and investments are vital to circumventing the low growth trap and supplying a qualified labor force to meet a predicted shortfall in trained professionals in the area of information technology and communication (ICT).

Digital transformation can be a powerful tool in overcoming productivity stagnation. In Brazil, the contribution of the ICT industry to GDP growth in 2020 was only 40 percent of its value to the United States, half of its value to China, and two-thirds in the case of the Eurozone.

Opportunities offered by the sustainable economy can provide an impetus for innovative activities, leading to productivity growth. In the case of Brazil, we view innovation as a primary lever for resolving serious structural problems, such as the challenges to sustainable development and a lack of social equity.

Ernesto José Gutierrez de Piñeres, Digital Vice President, Ecopetrol
Science, technology and innovation are key drivers unlocking productivity potential in uncertain times

Science, technology and innovation (STI) have become the key drivers accelerating Colombia's energy transition and facilitating the process of creating a more sustainable, inclusive and transparent economy. Innovative and disruptive solutions are fundamental to Colombia meeting its 2050 carbon reduction goals and for the transition to net-zero, a top priority at the national level.

As a key energy player, Ecopetrol recognizes the need to evolve quickly as it confronts major challenges to our industry. We aim to transition from a value chain to a value ecosystem, from estimation to measurement, and from traditional business models to knowledge exchange and collaboration. To achieve this, we need to collaborate with local and international innovation ecosystems and develop a more agile, efficient approach to handling energy needs and opportunities.

This is the reason why we at Ecopetrol joined the corporate network of the *Global Innovation Index* (GII) hosted by the Portulans Institute. The GII has allowed us to understand the dynamics of Colombia's innovation system and has fostered better informed, more balanced decision-making at a strategic level. Even though Colombia notablyimproved its innovation performance in the GII 2022 (Colombia ranks 63rd out of 132 countries) compared to the year before, the Index shows that Colombia produces fewer innovation outcomes than expected relative to its innovation input.

In order to instigate a meaningful change, business development goals must be balanced against safeguarding the planet and environment. At Ecopetrol, we are fully aware of this urgent imperative. Early this year, the Company presented its strategic vision for 2040 – "Energy that Transforms." This is a comprehensive response to current environmental, social and governance challenges (ESGs), with a sharp focus on generating sustainable value for all stakeholders. The Company seeks to build a better future by transforming ideas into opportunities through innovation and cutting-edge technology. That is why Ecopetrol decided to add a "T" to ESG to produce a set of TESG (technological, environmental, social and governance) targets, as a way to understand how technology can be at the heart of our business strategy.

Mustafa Gültepe, President, Turkish Exporters Assembly (TİM)
Improving Türkiye's exports and productivity through innovation

Recent advances in future technologies hold enormous potential for sustainable development and productivity growth. That is why this year's Special theme – "What is the future of innovation-driven growth?" – is extremely valuable for enhancing and strengthening our understanding of what is meant by efficiency.

In order to increase productivity – one of the main drivers of sustainable income growth and poverty reduction – countries should prioritize investments in innovation, including R&D, human capital and organizational knowledge accumulation. For this reason, the Turkish Exporters Assembly (TİM) – an umbrella organization for more than 100,000 exporters in Türkiye – continues to design projects that help exporters adapt to an age of digitalization and ensure they benefit from new technologies.

As a result of these efforts, 2021 was a record-breaking year for Turkish exports, which achieved a historical record in annual exports amounting to USD 225 billion. Significant advances in Turkish exports have increased economic prosperity within the country. Export-oriented investments have created employment opportunities for the younger generation and uplifted many Turkish cities economically.

Innovation is at the center of our work at TİM. We view innovation as the most valuable tool for catching up with the ever-changing structure of the global economy and ensuring that Türkiye is a notable market player. Projects developed within the scope of the TİM Innovation and Entrepreneurship Academy have sought innovative ideas and opened new horizons. Last year, Türkiye ranked 41st in the *Global Innovation Index* (GII), having climbed 10 positions from 2020 and has improved further to 37th place in 2022, recording the country's best result to date. Achieving this success was a joint effort carried out under the coordination of the Assembly, as well as relevant ministries and institutions. TİM aims to continue strengthening Türkiye's innovation ecosystem and maintaining the success achieved thus far.

On behalf of myself and the TİM, I would like to thank the President of the Republic of Türkiye and ministries, the GII Türkiye Task Force and all stakeholders who contributed to the production of this year's *Global Innovation Index 2022*, which gives a valuable perspective and offers important insights drawn from an ever-expanding knowledge-base on innovation, innovation policies and tackling productivity stagnation.

Corporate Network partners

Partnerships with the private sector are an important source of influence for the GII – firms, private sector entities, and industry associations keen to promote innovation and spur competitiveness, are after all, at the heart of innovation. These partners constitute the GII's Corporate Network, supported by the Portulans Institute. In 2022, the GII Corporate Network comprises the Confederation of Indian Industry (the longest-standing corporate partner since 2008), the Brazilian National Confederation of Industry (a partner since 2017), as well as Ecopetrol Group and the Turkish Exporters Assembly, which both joined last year. We extend our gratitude to all corporate partners for their invaluable support.

Brazilian National Confederation of Industry (CNI)
Robson Braga de Andrade, President; Gianna Sagazio, Innovation Director; Tatiana Farah de Mello, Innovation Executive Manager; Pedro Micussi, Industrial Development Specialist.

Confederation of Indian Industry (CII)
Chandrajit Banerjee, Director General; S. Raghupathy, Principal Adviser; Ashish Mohan, Principal Counsellor and Head, Technology, Innovation, R&D and IPR; Namita Bahl, Director, Technology, Innovation and R&D; Divya Arya, Executive Officer, Technology, Innovation and R&D.

Ecopetrol Group
Ernesto José Gutiérrez de Piñeres Luna, Digital Vice President; Alexis Ocampo, Technology Excellence Manager; Andrea Del Pilar Tapias, Coordinator of the Innovation Centers; Alicia Morales, Professional in Science, Technology and Innovation Strategy; Maria Clara Otálvaro, Innovation Trainee; Juan Pablo Fernandez, Science, Technology and Innovation Strategy Trainee.

Turkish Exporters Assembly (TİM)
Mustafa Gültepe, President; Kutlu Karavelioğlu, Deputy President; and the following Innovation and Sustainability Committee Members: Ahmet Fikret Kileci, Baran Çelik, Başaran Bayrak, Birol Celep, Erdem Çenesiz, Hüseyin Memişoğlu, İbrahim Pektaş, Mehmet Şanal, Melisa Tokgöz Mutlu, Nilgün Özdemir, Orhan Sabuncu. Bilal Bedir, Secretary General; Kübra Ulutaş, Deputy Secretary General; Meltem Demirtaş, Manager; Gökhan Ezgin, Chief; and the following experts: Gülçin Yetkin, Çağrı Köse, Burak Günaydın, Nebile Mercan.

Past corporate partners include Alcatel-Lucent, A.T. Kearney, Booz & Company, the Brazilian Micro and Small Business Support Service (SEBRAE), Canon, Dassault Systèmes, du (a telecommunications company), Huawei, IMP³rove – European Innovation Management Academy, PricewaterhouseCoopers (PwC), and strategy&.

Academic Network partners

First established in 2021, the GII Academic Network engages world-leading universities in GII research. Faculty members and graduate students – active in diverse fields, including business management, law, public policy and science – support the dissemination of GII results within the academic community. We extend our gratitude to all Academic Network partners for their support.

Brazil: University of São Paulo (USP), School of Economics, Management, Accounting and Actuarial Sciences, Moacir de Miranda Oliveira Júnior, Full Professor, Business Administration Department

China: Peking University, Office of Science and Technology Development, Weihao Yao, Director

Colombia: Universidad de los Andes, School of Management, Veneta Stefanova Andonova Zuleta, Dean; and Carolina Davila Aranda, International Office Director

Egypt: The American University in Cairo (AUC), School of Business, Sherif Kamel, Dean; and Nagla Rizk, Professor and Director, Access to Knowledge for Development Center

France: Institut Européen d'Administration des Affaires (INSEAD), Bruno Lanvin, Distinguished Fellow

Mexico: Tecnológico de Monterrey, EGADE Business School, Osmar Zavaleta, Associate Dean of Research; and José Ernesto Amorós, Professor and Research Group Leader, Entrepreneurship & Innovation

Nigeria: Lagos Business School Pan-Atlantic University (LBS), Chris Ogbechie, Dean

Russian Federation: National Research University Higher School of Economics (HSE University), Institute for Statistical Studies and Economics of Knowledge, Leonid Gokhberg, First Vice-Rector and Director

South Africa: The University of Johannesburg, College of Business and Economics, Erika Kraemer-Mbula, Professor of Economics

United Kingdom: Saïd Business School, University of Oxford, Soumitra Dutta, Dean

United States of America: Cornell SC Johnson College of Business, Ravi Kanbur, Professor, Charles H. Dyson School of Applied Economics and Management

Vietnam: VinUniversity, Rohit Verma, Founding Provost

GII 2022 at a glance

The Global Innovation Index 2022 captures the innovation ecosystem performance of 132 economies and tracks the most recent global innovation trends.

Global leaders in innovation in 2022

Top three innovation economies by region

Latin America and the Caribbean
1. **Chile**
2. **Brazil** ☆
3. **Mexico** ↓

Sub-Saharan Africa*
1. **South Africa**
2. **Botswana** ☆
3. **Kenya** ↓

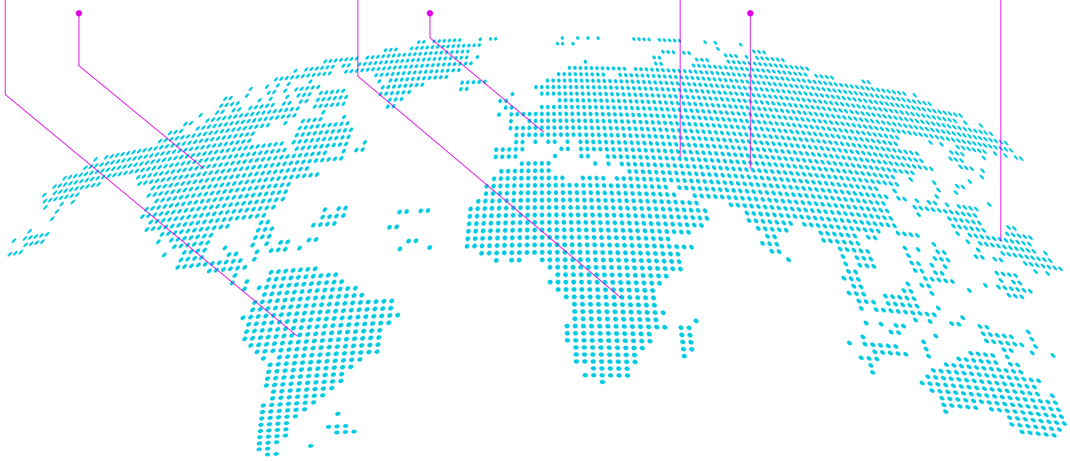
Northern Africa and Western Asia†
1. **Israel**
2. **United Arab Emirates**
3. **Türkiye**

South East Asia, East Asia, and Oceania
1. **Republic of Korea**
2. **Singapore**
3. **China**

Northern America
1. **United States**
2. **Canada**

Europe
1. **Switzerland**
2. **Sweden**
3. **United Kingdom**

Central and Southern Asia
1. **India**
2. **Iran (Islamic Republic of)**
3. **Uzbekistan** ☆



☆ Indicates a new entrant into the top three in 2022.

↑↓ Indicates the movement of rank (up or down) within the top three, relative to 2021.

* Top three in Sub-Saharan Africa (SSA) – excluding island economies. The top four in the region, including all economies, comprise Mauritius (1st), South Africa (2nd), Botswana (3rd) and Kenya (4th).

† Top three in Northern Africa and Western Asia (NAWA) – excluding island economies. The top four in the region, including all economies, are as follows: Israel (1st), Cyprus (2nd), United Arab Emirates (3rd) and Türkiye (4th).

Top three innovation economies by income group

High-income
1. **Switzerland**
2. **United States** ↑
3. **Sweden** ↓

Upper middle-income
1. **China**
2. **Bulgaria**
3. **Malaysia**

Lower middle-income
1. **India** ↑
2. **Viet Nam** ↓
3. **Iran (Islamic Republic of)** ☆

Low-income
1. **Rwanda**
2. **Madagascar** ☆
3. **Ethiopia** ☆

Source: Global Innovation Index Database, WIPO, 2022.

Notes: World Bank Income Group Classification (June 2021). Year-on-year GII rank changes are influenced by performance and methodological considerations; some economy data are incomplete (see Appendix I).

Global Innovation Index 2022 rankings

GII rank	Economy	Score	Income group rank	Region rank
1	Switzerland	64.6	1	1
2	United States	61.8	2	1
3	Sweden	61.6	3	2
4	United Kingdom	59.7	4	3
5	Netherlands	58.0	5	4
6	Republic of Korea	57.8	6	1
7	Singapore	57.3	7	2
8	Germany	57.2	8	5
9	Finland	56.9	9	6
10	Denmark	55.9	10	7
11	China	55.3	1	3
12	France	55.0	11	8
13	Japan	53.6	12	4
14	Hong Kong, China	51.8	13	5
15	Canada	50.8	14	2
16	Israel	50.2	15	1
17	Austria	50.2	16	9
18	Estonia	50.2	17	10
19	Luxembourg	49.8	18	11
20	Iceland	49.5	19	12
21	Malta	49.2	20	13
22	Norway	48.8	21	14
23	Ireland	48.5	22	15
24	New Zealand	47.2	23	6
25	Australia	47.1	24	7
26	Belgium	46.9	25	16
27	Cyprus	46.2	26	2
28	Italy	46.1	27	17
29	Spain	44.6	28	18
30	Czech Republic	42.8	29	19
31	United Arab Emirates	42.1	30	3
32	Portugal	42.1	31	20
33	Slovenia	40.6	32	21
34	Hungary	39.8	33	22
35	Bulgaria	39.5	2	23
36	Malaysia	38.7	3	8
37	Türkiye	38.1	4	4
38	Poland	37.5	34	24
39	Lithuania	37.3	35	25
40	India	36.6	1	1
41	Latvia	36.5	36	26
42	Croatia	35.6	37	27
43	Thailand	34.9	5	9
44	Greece	34.5	38	28
45	Mauritius	34.4	6	1
46	Slovakia	34.3	39	29
47	Russian Federation	34.3	7	30
48	Viet Nam	34.2	2	10
49	Romania	34.1	8	31
50	Chile	34.0	40	1
51	Saudi Arabia	33.4	41	5
52	Qatar	32.9	42	6
53	Iran (Islamic Republic of)	32.9	3	2
54	Brazil	32.5	9	2
55	Serbia	32.3	10	32
56	Republic of Moldova	31.1	11	33
57	Ukraine	31.0	4	34
58	Mexico	31.0	12	3
59	Philippines	30.7	5	11
60	Montenegro	30.3	13	35
61	South Africa	29.8	14	2
62	Kuwait	29.2	43	7
63	Colombia	29.2	15	4
64	Uruguay	29.2	44	5
65	Peru	29.1	16	6
66	North Macedonia	28.8	17	36

GII rank	Economy	Score	Income group rank	Region rank
67	Morocco	28.8	6	8
68	Costa Rica	28.7	18	7
69	Argentina	28.6	19	8
70	Bosnia and Herzegovina	28.5	20	37
71	Mongolia	28.0	7	12
72	Bahrain	28.0	45	9
73	Tunisia	27.9	8	10
74	Georgia	27.9	21	11
75	Indonesia	27.9	9	13
76	Jamaica	27.7	22	9
77	Belarus	27.5	23	38
78	Jordan	27.4	24	12
79	Oman	26.8	46	13
80	Armenia	26.6	25	14
81	Panama	25.7	26	10
82	Uzbekistan	25.3	10	3
83	Kazakhstan	24.7	27	4
84	Albania	24.4	28	39
85	Sri Lanka	24.2	11	5
86	Botswana	23.9	29	3
87	Pakistan	23.0	12	6
88	Kenya	22.7	13	4
89	Egypt	22.7	14	15
90	Dominican Republic	22.7	30	11
91	Paraguay	22.7	31	12
92	Brunei Darussalam	22.2	47	14
93	Azerbaijan	21.5	32	16
94	Kyrgyzstan	21.1	15	7
95	Ghana	20.8	16	5
96	Namibia	20.6	33	6
97	Cambodia	20.5	17	15
98	Ecuador	20.3	34	13
99	Senegal	19.9	18	7
100	El Salvador	19.9	19	14
101	Trinidad and Tobago	19.8	48	15
102	Bangladesh	19.7	20	8
103	United Republic of Tanzania	19.4	21	8
104	Tajikistan	18.8	22	9
105	Rwanda	18.7	1	9
106	Madagascar	18.6	2	10
107	Zimbabwe	18.1	23	11
108	Nicaragua	18.1	24	16
109	Côte d'Ivoire	17.8	25	12
110	Guatemala	17.8	35	17
111	Nepal	17.6	26	10
112	Lao People's Democratic Republic	17.4	27	16
113	Honduras	17.3	28	18
114	Nigeria	16.9	29	13
115	Algeria	16.7	30	17
116	Myanmar	16.4	31	17
117	Ethiopia	16.3	3	14
118	Zambia	15.8	32	15
119	Uganda	15.7	4	16
120	Burkina Faso	15.3	5	17
121	Cameroon	15.1	33	18
122	Togo	15.1	6	19
123	Mozambique	15.0	7	20
124	Benin	14.6	34	21
125	Niger	14.6	8	22
126	Mali	14.2	9	23
127	Angola	13.9	35	24
128	Yemen	13.8	10	18
129	Mauritania	12.4	36	25
130	Burundi	12.3	11	26
131	Iraq	11.9	36	19
132	Guinea	11.6	12	27

- High-income
- Upper middle-income
- Lower middle-income
- Low-income
- Europe
- Northern America
- Latin America and the Caribbean
- South East Asia, East Asia, and Oceania
- Central and Southern Asia
- Northern Africa and Western Asia
- Sub-Saharan Africa

Source: Global Innovation Index Database, WIPO, 2022.

Note: For an explanation of classifications, see Economy Profiles, note 1.

Innovation performance at different income levels, 2022

	High-income group	Upper middle-income group	Lower middle-income group	Low-income group
Performance above expectation for level of development	Switzerland United States Sweden United Kingdom Netherlands Republic of Korea Singapore Germany Finland Denmark France Japan Hong Kong, China Canada Israel Austria Estonia Luxembourg Iceland Malta Norway Ireland New Zealand Australia	China Bulgaria Thailand Brazil Republic of Moldova South Africa Peru Jamaica Jordan	India Viet Nam Iran (Islamic Republic of) Ukraine Philippines Morocco Mongolia Tunisia Indonesia Uzbekistan Pakistan Kenya United Republic of Tanzania Zimbabwe	Rwanda Madagascar Mozambique Burundi
Performance in line with level of development	Belgium Cyprus Italy Spain Czech Republic Portugal Slovenia Hungary Poland Latvia Croatia Chile	Malaysia Türkiye Mauritius Russian Federation Serbia Mexico Montenegro Colombia North Macedonia Costa Rica Bosnia and Herzegovina Georgia Armenia Albania	Sri Lanka Kyrgyzstan Ghana Cambodia Senegal Bangladesh Tajikistan Nepal	Ethiopia Uganda Burkina Faso Togo Niger Yemen
All other economies	United Arab Emirates Lithuania Greece Slovakia Saudi Arabia Qatar Kuwait Uruguay Bahrain Oman Brunei Darussalam Trinidad and Tobago	Romania Argentina Belarus Panama Kazakhstan Botswana Dominican Republic Paraguay Azerbaijan Namibia Ecuador Guatemala Iraq	Egypt El Salvador Nicaragua Côte d'Ivoire Lao People's Democratic Republic Honduras Nigeria Algeria Myanmar Zambia Cameroon Benin Angola Mauritania	Mali Guinea

Source: Global Innovation Index Database, WIPO, 2022.

Key takeaways

The GII 2022 tracks global innovation trends against the background of an ongoing pandemic, a slowing of productivity growth and other evolving challenges.

The state of innovation in turbulent times

1. Innovation investments thrived at the height of the COVID-19 pandemic and boomed in 2021, but their continued resilience is uncertain for 2022, as the world meets new challenges

Historic data, plus the global economic recession, would have led one to expect a prompt cutback in research and development (R&D), intellectual property (IP) filings and venture capital in 2020 and 2021. The opposite happened:

- Scientific articles published globally surpassed the 2 million mark for the first time in 2021.
- Investments in global R&D in 2020 grew at a rate of 3.3 percent, not falling, but slowing from the historically high 6.1 percent R&D growth rate recorded in 2019.
- Government budget allocations for the top R&D spending economies showed strong growth in 2020, as governments vigorously sought to mitigate the economic effects of the crisis on the future of innovation. For 2021 R&D budgets, the picture is more varied, with government spending having continued to grow in the Republic of Korea and Germany, but being cut by Japan and the United States.
- In turn, top corporate R&D spenders increased their R&D expenditure by more than 11 percent in 2020, and by almost 10 percent to over USD 900 billion in 2021, which is higher than in 2019 before the pandemic. This increase was primarily driven by four industries: ICT hardware and electrical equipment; Software and ICT services; Pharmaceuticals and biotechnology; and, Construction and industrial metals. Firms that cut R&D in 2020, including in sectors such as Automobiles; Industrial engineering and transportation; and Travel, generally – but not always – returned to R&D growth in 2021.
- IP filing activity grew during the global pandemic in 2020 and in 2021, too. International trademark filings – a good proxy for entrepreneurship – saw particularly strong growth in 2021, up by 15 percent.
- The biggest boom was in venture capital (VC). VC deals grew by 46 percent in 2021, recording levels comparable to the internet boom years of the late 1990s. What is more, VC has become more inclusive, with the Latin America and the Caribbean and Africa regions witnessing the strongest VC growth, albeit from a low base. The VC outlook for 2022 is more sober; tightening monetary policies and the knock-on effect on risk capital will lead to a deceleration in VC.

2. Technological progress, adoption and innovation's socioeconomic impact all show signs of weakness – the future of innovation-driven growth is at stake

- Indicators of *technological progress* in the fields of semiconductor speed, electric battery prices, the cost of renewable energy (with the exception of wind) and drug approvals in the United States – the best proxy to hand – show a slowdown from long-term trends.
- *Technology adoption*, in turn, is progressing, with growth across a variety of technologies analyzed, in particular electric vehicles. However, penetration rates are still medium-to-low, with the exception of mobile broadband, which is now within reach of the vast majority of people worldwide.
- Largely due to COVID-19's short-term influence, the *socioeconomic impact of innovation* seems to be at a low point. All proxies for innovation impact are experiencing a significant slowdown. Today, productivity growth – the metric used by economists to gauge whether living standards can be improved over time – is at its lowest level ever. What has been called the period of Great Stagnation brings into question the ability of innovation to create future growth.
- The thematic focus of this year's 2022 report considers this sober outlook and asks: "What is the future of innovation-driven growth?" and "Who is right?". Is it the innovation pessimists, who argue that low productivity growth is here to stay. According to them, innovations that make a truly transformative impact on productivity – like some of the key inventions of previous centuries such as electricity – are just too difficult to find these days. Or is it the innovation optimists, who predict a new economic and social era; one where a massive new innovation spurt fosters a productivity uplift.

- Taking the view of the optimists, the GII 2022 puts its hopes in two novel innovation waves:
  1. an upcoming **Digital Age innovation wave** built on supercomputing, artificial intelligence and automation that is on the verge of making ample productivity impacts across all sectors – including services – and helping to achieve scientific breakthroughs in basic sciences of all fields; and
  2. a **Deep Science innovation wave** built on breakthroughs in biotechnologies, nanotechnologies, new materials and other sciences that is revolutionizing innovations in four fields of key importance to society: health, food, environment, and mobility.

That said, the positive effects of these two novel waves will take a long time to materialize. Many obstacles, particularly in the area of technology adoption and diffusion, have to be overcome first.

On balance, if the Digital Age and Deep Science innovation waves can be deployed effectively, and if governments address the urgent matters discussed in the GII 2022 Special theme section, then innovation-driven productivity growth and its effect on our well-being will be high.

Results of the *Global Innovation Index 2022* rankings

3. Some key changes in the top 15 GII ranking; China, Türkiye and India consolidate their position as global innovation powerhouses; Indonesia next up?

- Switzerland – for the 12th year in a row – ranks first in the GII 2022. The United States climbs to 2nd position.
- Then comes Sweden, which is followed, in turn, by the United Kingdom, the Netherlands and the Republic of Korea.
- China moves up to 11th place, overtaking France; for now, it firmly remains the only middle-income economy within the GII top 30. No change to China's exceptional position among middle-income economies is currently in sight, unless Türkiye further progresses fast.
- Canada is back among the top 15 global innovators, climbing to 15th place.
- South East Asia, East Asia, and Oceania (SEAO) is the only region closing the gap on Northern America and Europe. Two SEAO economies are among the top 10 global innovators: the Republic of Korea (6th) and Singapore (rising to rank 7th place).
- Türkiye (37th) and India (40th) enter the top 40 for the first time.
- Beyond China and India, Viet Nam (48th), the Islamic Republic of Iran (53rd) and the Philippines (59th) are the middle-income economies with the fastest innovation catch-up to-date, although Viet Nam and the Philippines fell back slightly, underlining the importance of sustaining innovation effort over time. Indonesia (75th), in its turn, shows promising innovation potential.
- The top economies within the Northern Africa and Western Asia region are Israel (16th), the United Arab Emirates (31st and edging closer to the top 30) and Türkiye.
- India, the Islamic Republic of Iran and – for the first time – Uzbekistan (82nd) and Pakistan (87th) lead the Central and Southern Asia region.
- Chile (50th) – the only Latin American country in the top 50 – leads the Latin America and Caribbean region, followed by Brazil (54th) – a newcomer to the region's top 3 – then Mexico (58th), with Costa Rica dropping out of the top 3 for the region (68th). Colombia (63rd), Peru (65th), Argentina (69th) and the Dominican Republic (90th) all see substantial rank increases in the GII 2022.
- Mauritius (45th) and South Africa (61st) lead the Sub-Sahara Africa region, followed by newcomer to the regional top 3 Botswana (86th) and then Kenya (88th). Beyond Mauritius and Botswana, Ghana (95th), Namibia (96th), Senegal (99th), Zimbabwe (107th), Ethiopia (117th) and Angola (127th) jump forward.

4. Several developing economies are performing above expectation on innovation relative to their level of economic development

- In the GII 2022, 26 countries are outperforming on innovation relative to their development, including newcomers Indonesia, Uzbekistan and Pakistan.
- India, Kenya, the Republic of Moldova and Viet Nam hold the record by outperforming for the 12th year in a row.
- Of the 26 outperformers on innovation, eight are from Sub-Saharan Africa, with Kenya, Rwanda and Mozambique in the lead.
- In Latin America and the Caribbean, Brazil, Peru and Jamaica are outperforming relative to development.

5. China now has the same amount of global top S&T clusters as the United States

- In 2022 – as in previous years – the top 100 science and technology (S&T) clusters are concentrated in three regions – Northern America, Europe and Asia – and in two countries especially: China and the United States.
- Tokyo–Yokohama (Japan) is the top global S&T cluster, followed by Shenzhen–Hong Kong–Guangzhou (China and Hong Kong, China), Beijing (China), Seoul (Republic of Korea) and San Jose–San Francisco (United States).
- Cambridge in the United Kingdom and Eindhoven in the Netherlands/Belgium are found to be the most S&T-intensive clusters. Daejeon (Republic of Korea), San Jose–San Francisco (United States) and Oxford (United Kingdom) follow.
- For the first time, China has as many top 100 S&T clusters as the United States. Germany follows with 10 clusters, headed by Cologne and Munich, and Japan with five clusters, with Tokyo–Yokohama and Osaka–Kobe–Kyoto in the lead.
- São Paulo (Brazil); Bengaluru, Delhi and Mumbai and – new – Chennai (India); Tehran (Islamic Republic of Iran); Istanbul and Ankara (Türkiye); and Moscow (Russian Federation) are the only clusters from middle-income economies beyond China. Ankara and Istanbul (Türkiye) and Mumbai (India) have increased their ranking considerably.
- The GII 2022 also identifies clusters beyond the top 100. Among middle-income economies, Argentina, Egypt, Malaysia, Mexico and Thailand host S&T clusters, respectively, Buenos Aires, Cairo, Kuala Lumpur, Mexico City and Bangkok. Other prominent Latin American urban areas – such as Mexico City, Rio de Janeiro, Porto Alegre and Santiago de Chile – also feature in this extended global S&T clusters top ranking.

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.

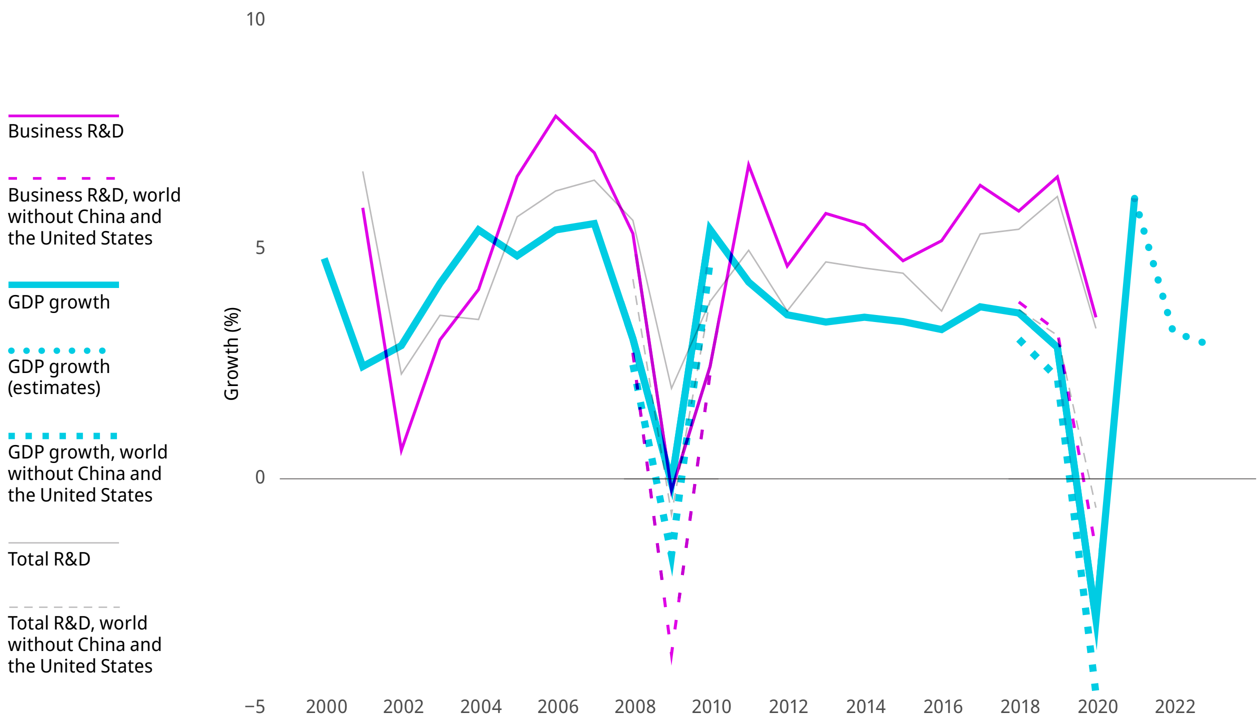
Early indications in 2022, however, point to possible challenges to come. While innovation was resilient in 2020 and flourishing in 2021, in line with the global recovery, the second external shock coming so soon afterwards, together constituting a real double-whammy, might be more complicated to overcome.

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.

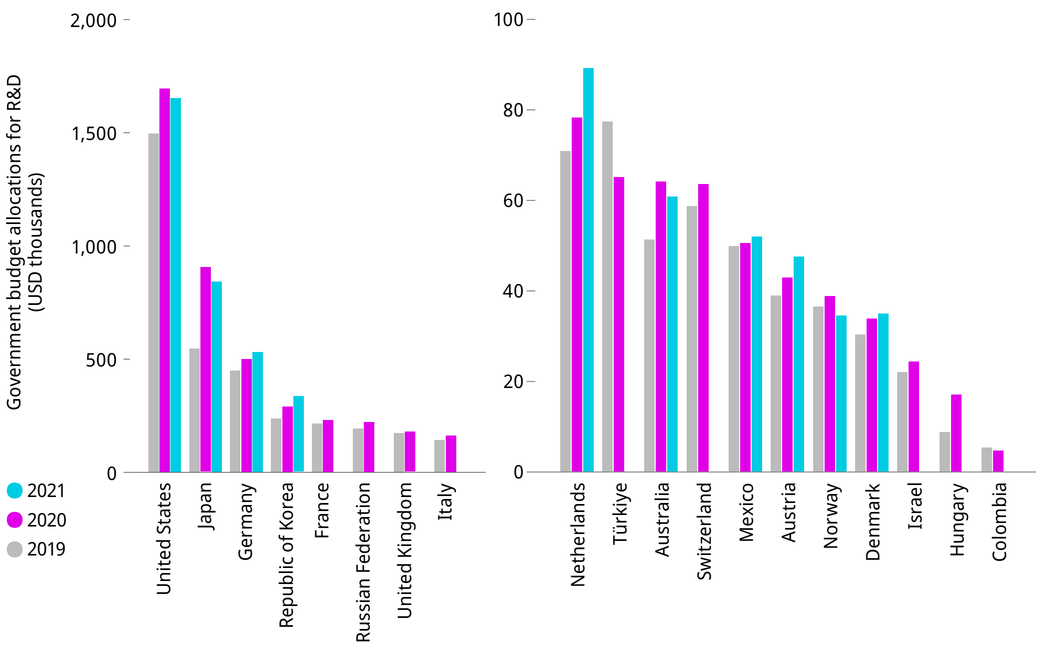
Official R&D data for the full 2021 calendar year will only be available by the first half of 2023 and it will be presented in the next edition of the GII, with full data on R&D in 2022 available in 2024.

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.

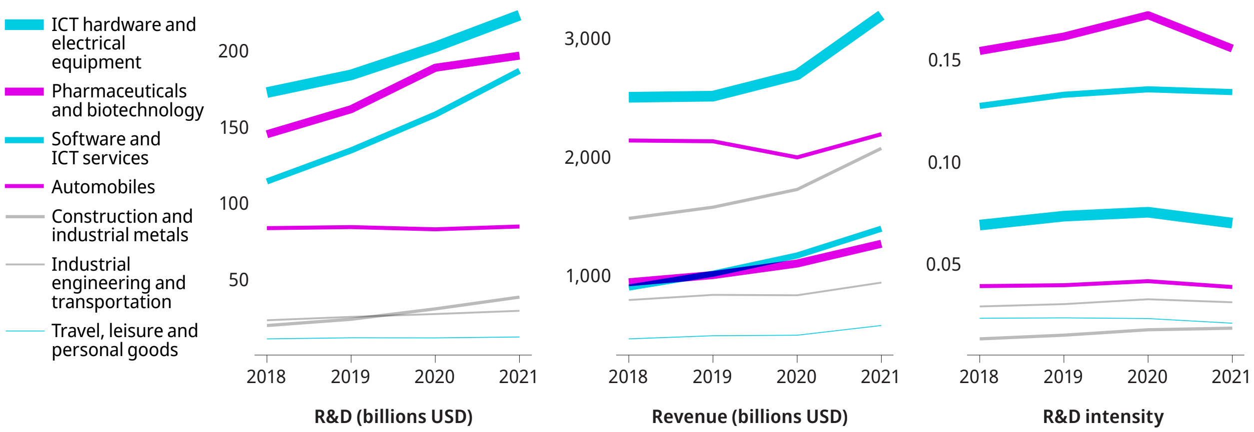
Table 1 R&D and revenue growth of the top global corporate R&D spenders, 2018–2021

	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

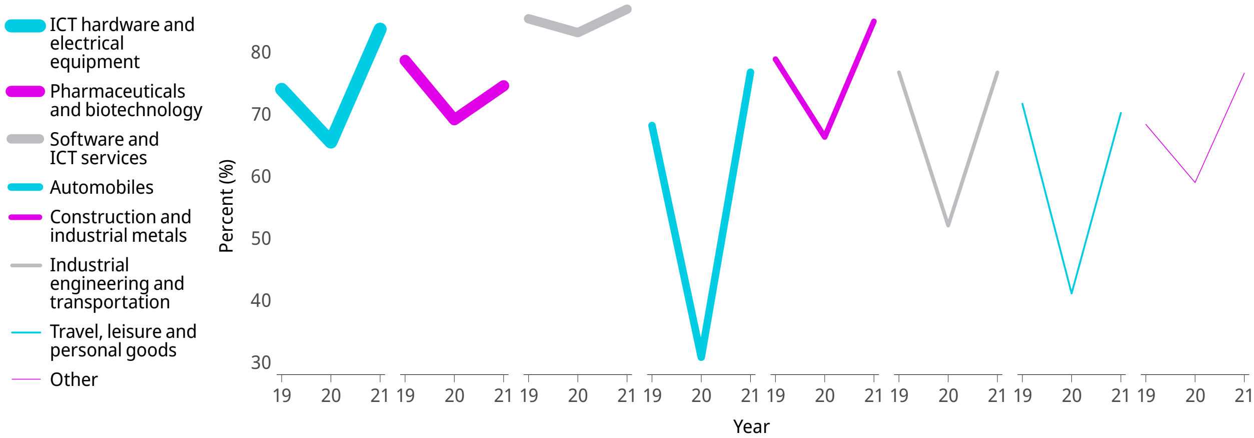


Source: WIPO, based on BvD Orbis database.

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.

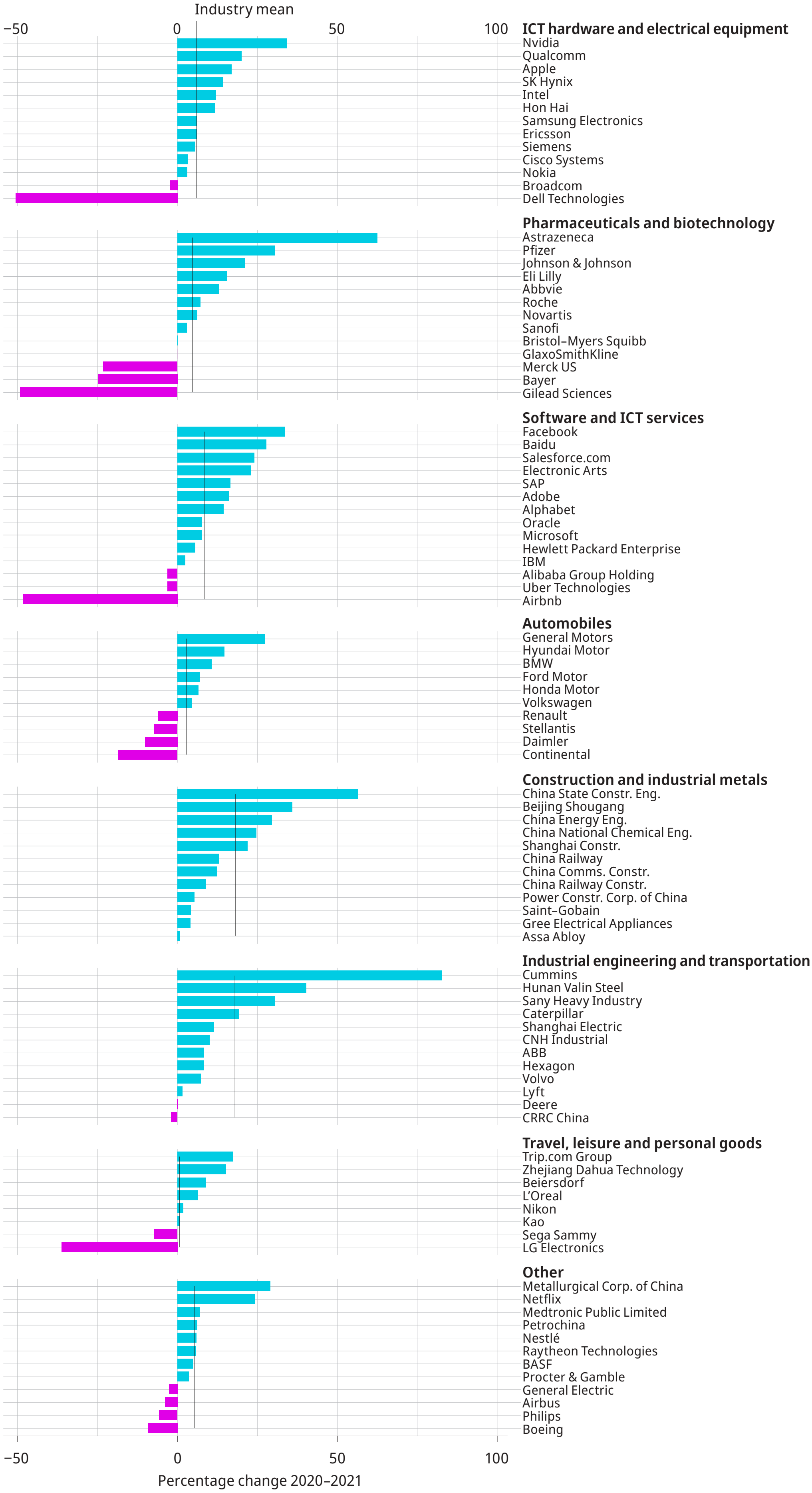
Intellectual property filings

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.

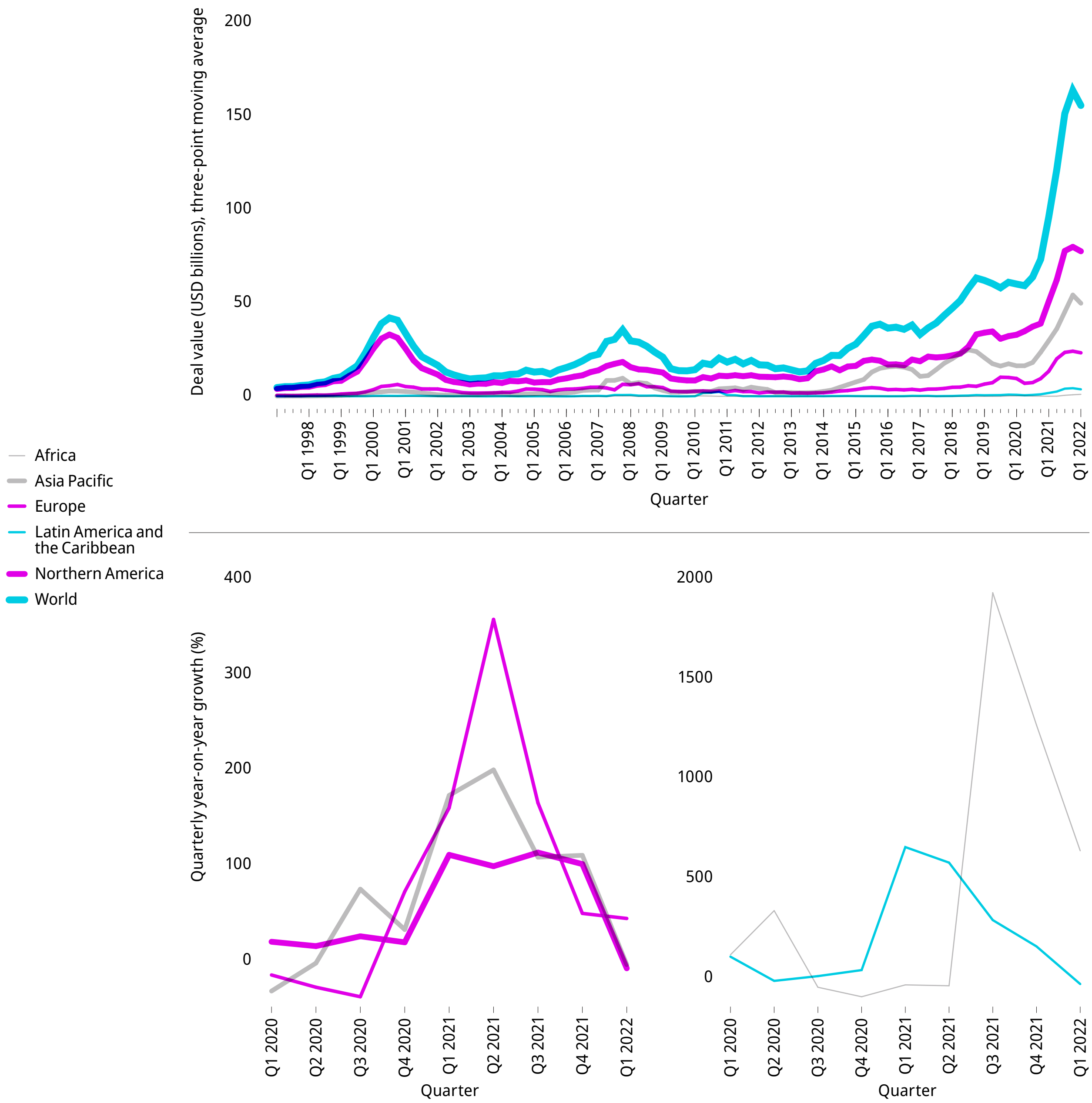
Financial services dominate Latin America's startup scene and this is clearly reflected in the top 10 most valued VC deals in the region (which received USD 4 billion of the USD 15.7 billion). Five of the top 10 deals were sealed by fintech companies, such as Nubank, which now has more customers than 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

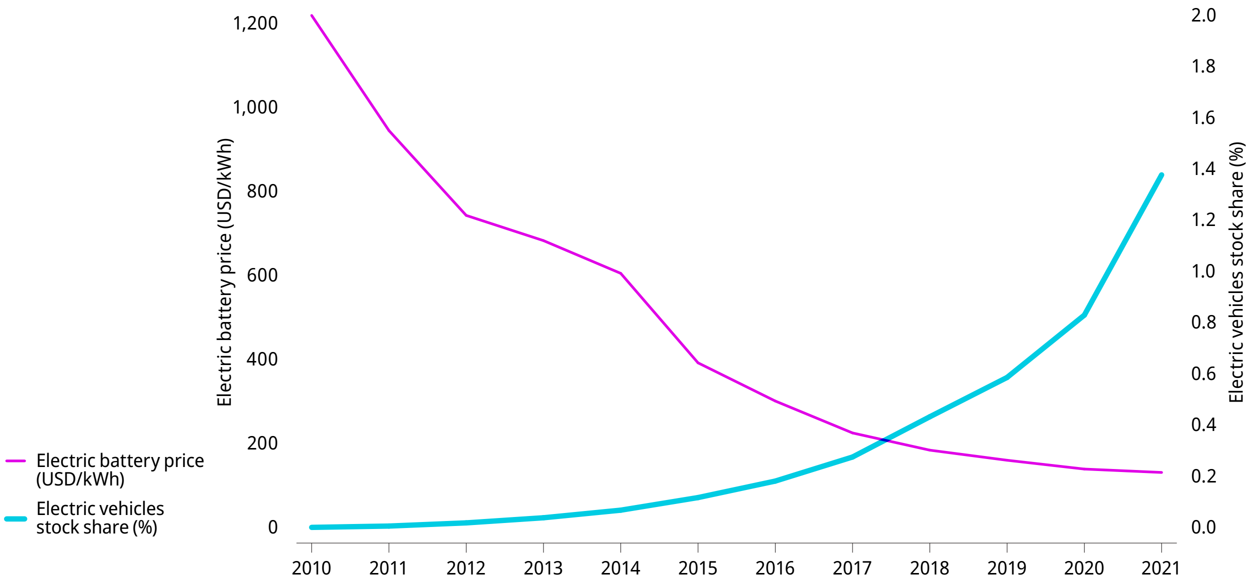
Moore's law famously predicted that the speed and capability of our personal computers (measured by the number of transistors on microchips) would double every two years. This prediction has proved roughly true since the 1970s but does it still hold? Over the past 10 years, technological progress has 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.

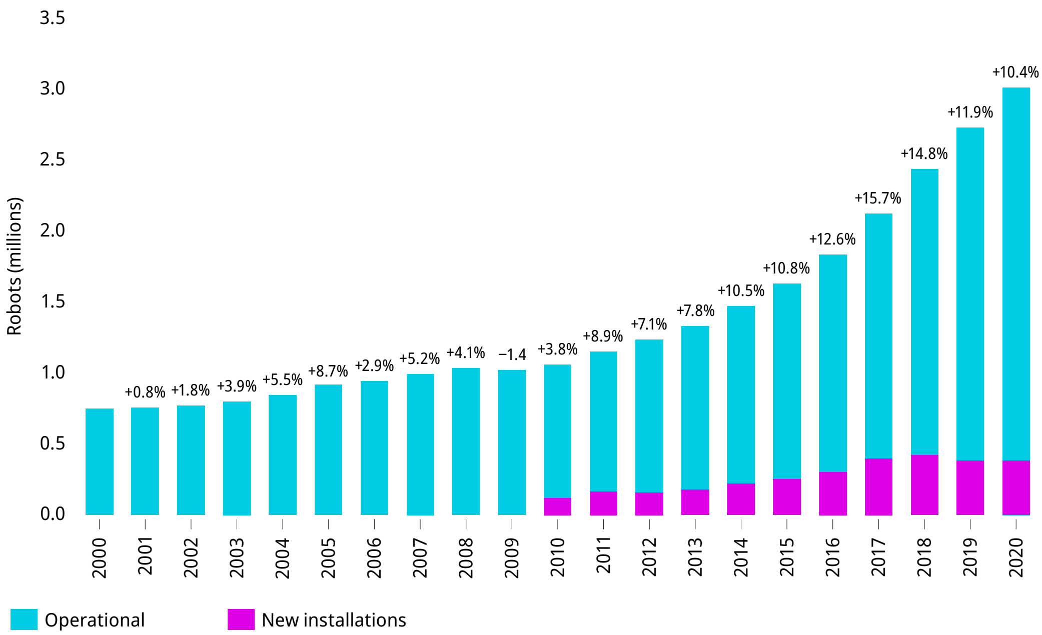
Robots and automatization
The stock of industrial robots deployed worldwide reached the 3 million mark in 2020 (see Figure 8), up from 1 million in 2010 and 0.8 million in 2000. This represents a 10.4 percent increase compared to 2019 and is similar to the average annual growth rate of 11 percent since 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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GII 2022 results

The GII reveals the most innovative economies in the world, ranking the innovation performance of 132 economies.

What follows are highlights of the *Global Innovation Index 2022* (GII) ranking. Appendix I provides details on how to interpret and analyze the results, particularly with regard to any year-on-year comparison of GII rankings, which requires cautious interpretation. Box 2 describes the process involved in using the GII to improve an economy's innovation performance.

The GII 2022 innovation leaders

Only a small number of economies have consistently delivered peak innovation performance

For a twelfth consecutive year, Switzerland ranks first in the GII (Figure 9). The United States of America (US) overtakes Sweden to climb to 2nd position, and continues to head the league table of scoring best in the world on 15 of the 81 GII 2022 innovation indicators (Box 1). Germany reaches 8th position, its highest ranking since 2009, after having entered the top 10 in 2016. Singapore bounces back to 7th position.

China continues its ascent toward the top 10, reaching 11th position in 2022. China remains the only middle-income economy within the top 30, keeping its 3rd place within the South East Asia, East Asia, and Oceania (SEAO) region and staying in 1st place in the upper middle-income group (see Figure 10 and Table 2). Canada (15th) returns to the top 15 for the first time since 2016 having dropped out of the top 10 in 2012.

Among the top 25 economies, Estonia (18th) makes notable progress this year, as do the United Arab Emirates (UAE) (31st) and Poland (38th).

Apart from China, there are only four other middle-income economies among the top 40 economies for innovation. Bulgaria (35th) and Malaysia (36th) keep the same rank as in 2021. In addition, Türkiye and India enter the top 40 for the first time, placed 37th and 40th, respectively. India overtakes Viet Nam (48th) as the top lower middle-income economy for innovation.

Chile (50th) makes it back into the top 50 – its best ranking since 2018 – making it first for innovation in Latin America and the Caribbean once again. For the first time ever, Brazil (54th) is among the top 3 for the region, scoring 2nd and displacing Mexico (58th), which drops to 3rd and losing three ranks in 2022. Costa Rica, in turn, exits the regional top 3, ranking 68th overall in innovation, down 12 ranks in 2022. Other notable improvers in the global innovation ranking for the region are Colombia (63rd), Peru (65th), Argentina (69th) and the Dominican Republic (90th). Peru positions itself as a global leader this year in the indicators availability of Loans from microfinance institutions (1st), Graduates in science and engineering (18th) and Utility models (22nd).

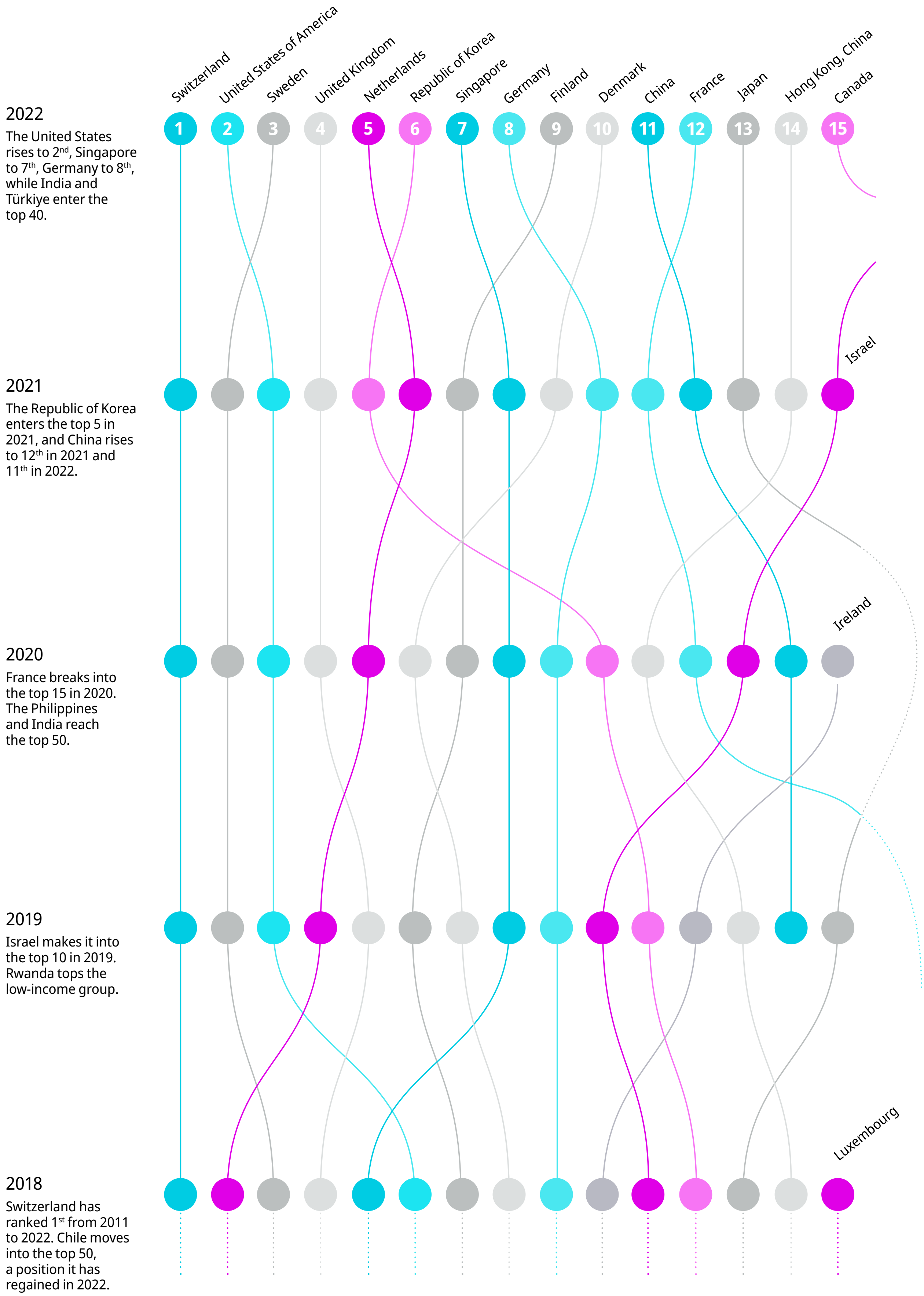
The Islamic Republic of Iran makes a big leap, reaching the 53rd position; it takes 3rd position among the lower middle-income group. Indonesia takes a big jump into the top 80 in 2022, ranking 75. Uzbekistan continues moving ahead and reaches the 82nd position in 2022, placing it among the top 3 economies for the Central and Southern Asia (CSA) region, having re-entered the GII only in 2020 due to its better innovation data availability.

Pakistan is a prominent climber in the GII 2022 ranking, entering the top 90 at 87th place.

This year, Indonesia, Uzbekistan and Pakistan entered the group of Innovation Achievers for the first time by performing above expectation on innovation for their level of economic development (see Table 3 and Figure 11).

Sixteen out of the 25 economies from Sub-Saharan Africa covered this year improved their ranking. Botswana took the biggest leap forward, reaching 86th position, and in so doing overtaking Kenya (88th) among the top 3 for the region. Other notable improvers within the region are Mauritius (45th), Ghana (95th), Namibia (96th) and Senegal (99th). South Africa remains unchanged in 61st place – and continuing to fail to improve consistently over time.

Figure 9 Movement in the GII, top 10, 2018–2022



Source: Global Innovation Index Database, WIPO, 2022.

Note: Year-on-year comparisons of the GII ranks are influenced by changes in the GII model, as well as data availability.

Figure 10 Global leaders in innovation in 2022

Top three innovation economies by region

Europe

1 Switzerland
2 Sweden
3 United Kingdom

Northern America

1 United States
2 Canada

Latin America and the Caribbean

1 Chile
2 Brazil ☆
3 Mexico ↓

Central and Southern Asia

1 India
2 Iran (Islamic Republic of)
3 Uzbekistan ☆

South East Asia,East Asia, and Oceania

1 Republic of Korea
2 Singapore
3 China

Northern Africa and Western Asia†

1 Israel
2 United Arab Emirates
3 Türkiye

Sub-Saharan Africa*

1 South Africa
2 Botswana ☆
3 Kenya ↓

Top three innovation economies by income group

High-income

1 Switzerland
2 United States ↑
3 Sweden ↓

Upper middle-income

1 China
2 Bulgaria
3 Malaysia

Lower middle-income

1 India ↑
2 Viet Nam ↓
3 Iran (Islamic Republic of) ☆

Low-income

1 Rwanda
2 Madagascar ☆
3 Ethiopia ☆

☆ Indicates a new entrant into the top three in 2022.

↑↓ Indicates the movement of rank (up or down) within the top three, relative to 2021.

* Top three in Sub-Saharan Africa (SSA) – excluding island economies. The top four in the region, including all economies, comprise Mauritius (1st), South Africa (2nd), Botswana (3rd) and Kenya (4th).

† Top three in Northern Africa and Western Asia (NAWA) – excluding island economies. The top four in the region, including all economies, are as follows: Israel (1st), Cyprus (2nd), United Arab Emirates (3rd) and Türkiye (4th).

Source: Global Innovation Index Database, WIPO, 2022.

Notes: World Bank Income Group Classification (June 2021). Year-on-year GII rank changes are influenced by performance and methodological considerations; some economy data are incomplete (see Appendix I).

Box 1 **The United States continues to lead in several key innovation indicators. Singapore, China, Hong Kong (China) and Israel follow**

The United States still leads in terms of the number of GII innovation indicators for which it ranks top globally, ranking 1st in the world on 15 out of the 81 indicators used, two more than in 2021. It is number one in the world in indicators such as Global corporate R&D investors, Venture capital investors, the quality of its universities, the quality and impact of its scientific publications (H-index), the number of Patents by origin, computer software spending, and the value of corporate Intangible asset intensity.

Singapore follows the United States globally and is number one in the world on 11 indicators in total, one up from 2021, including leading in the indicators Government effectiveness, ICT access, Venture capital investors, High-tech manufacturing and GitHub commits. China, Hong Kong (China) and Israel tie jointly in 3rd place, attaining top ranking in Trademarks, High-tech imports and R&D expenditure, respectively. They are followed by Malta in 6th place, leading in Joint venture/strategic alliance deals. The Republic of Korea is in 7th, leading in number of researchers. Japan and Cyprus tie in 8th place, ranking 1st in Patent families and Mobile app creation. Finally, Switzerland, Estonia and Iceland share jointly the 10th position, leading in PCT patents, New businesses and ICT use, respectively.

Box Table 1 **Economies with the most top-ranked GII indicators, 2022**

	Innovation indicators that economies score best in worldwide		
Economy	Inputs	Outputs	Total
United States	9	6	15
Singapore	8	3	11
China	3	6	9
Hong Kong, China	6	3	9
Israel	7	2	9
Malta	4	4	8
Republic of Korea	4	3	7
Japan	3	3	6
Cyprus	4	2	6
Switzerland	2	3	5
Estonia	4	1	5
Iceland	3	2	5

Source: Global Innovation Index Database, WIPO, 2022.
Note: The GII methodology allows multiple economies to rank 1st on an indicator; see Economy profiles and Appendix I.

A changing global innovation landscape

Middle-income economies China, Türkiye and India continue to change the innovation landscape; others like the Islamic Republic of Iran and Indonesia show promising potential

Apart from group leaders China, Bulgaria and Malaysia, Türkiye (37th) and India (40th) are the two other middle-income economies to make it into the top 40. Thailand (43rd), Mauritius (45th), the Russian Federation (47th), Viet Nam (48th) and Romania (49th) make into the top 50, but with only Mauritius moving up the ranking this year.

Among the middle-income group, the Islamic Republic of Iran (53rd) and Indonesia (75th) have notably improved their ranking, not only this year but also over the past decade, and join Türkiye, Viet Nam and the Philippines (59th) in having an increasingly important potential for transforming the global innovation landscape.

Morocco (67th) has shown innovation potential for a number of years, whereas Pakistan (87th) and Cambodia (97th) are also starting to show signs of increased innovation potential.

India overtakes Viet Nam as leader of the lower middle-income group (Table 2). It continues to lead the world in the ICT services exports indicator (1st) and hold top rankings in other indicators, including Venture capital recipients' value (6th), Finance for startups and scaleups (8th), Graduates in science and engineering (11th), Labor productivity growth (12th) and Domestic industry diversification (14th).

Beyond the top 100, Bangladesh (102nd), Myanmar (116th) and Ethiopia (117th) have made the most progress in the rankings, increasing between nine and 14 positions overall. Bangladesh performs relatively well in Creative outputs, whereas Ethiopia does well in Knowledge and technology outputs – leading in Labor productivity growth (6th) and Utility models (19th).

Rwanda (105th) maintains in 1st position among the low-income group, while Madagascar (106th) and Ethiopia (117th) claim 2nd and 3rd position, respectively (Table 2). Tajikistan ranks 104th overall, and 22nd among the lower middle-income group, its new income classification.

Table 2 10 best-ranked economies by income group (rank)

Rank	Global Innovation Index 2022	Rank	Global Innovation Index 2022
High-income economies (48 in total)		**Upper middle-income economies (36 in total)**	
1	Switzerland (1)	1	China (11)
2	United States (2)	2	Bulgaria (35)
3	Sweden (3)	3	Malaysia (36)
4	United Kingdom (4)	4	Türkiye (37)
5	Netherlands (5)	5	Thailand (43)
6	Republic of Korea (6)	6	Mauritius (45)
7	Singapore (7)	7	Russian Federation (47)
8	Germany (8)	8	Romania (49)
9	Finland (9)	9	Brazil (54)
10	Denmark (10)	10	Serbia (55)
Lower middle-income economies (36 in total)		**Low-income economies (12 in total)**	
1	India (40)	1	Rwanda (105)
2	Viet Nam (48)	2	Madagascar (106)
3	Iran (Islamic Republic of) (53)	3	Ethiopia (117)
4	Ukraine (57)	4	Uganda (119)
5	Philippines (59)	5	Burkina Faso (120)
6	Morocco (67)	6	Togo (122)
7	Mongolia (71)	7	Mozambique (123)
8	Tunisia (73)	8	Niger (125)
9	Indonesia (75)	9	Mali (126)
10	Uzbekistan (82)	10	Yemen (128)

Source: Global Innovation Index Database, WIPO, 2022.

Innovation overperformers

Several developing economies are performing above expectation on innovation relative to their level of economic development

In the GII 2022, 26 economies are performing above expectation, relative to their level of development – these are the GII Innovation Achievers (Figure 11 and Table 3).

India, Kenya, the Republic of Moldova and Viet Nam continue as record holders by being Innovation Achievers for a 12th consecutive year. India's innovation performance is above average for the upper middle-income group in almost every innovation pillar, with the exception of Infrastructure, where it scores below average. Kenya (88th) scores above its income group in Institutions, Business sophistication, Knowledge and technology outputs, and Creative outputs. Viet Nam continues to score above the lower middle-income group average in all pillars, and even scores above average for the upper middle-income group in every pillar, apart from Human capital and research.

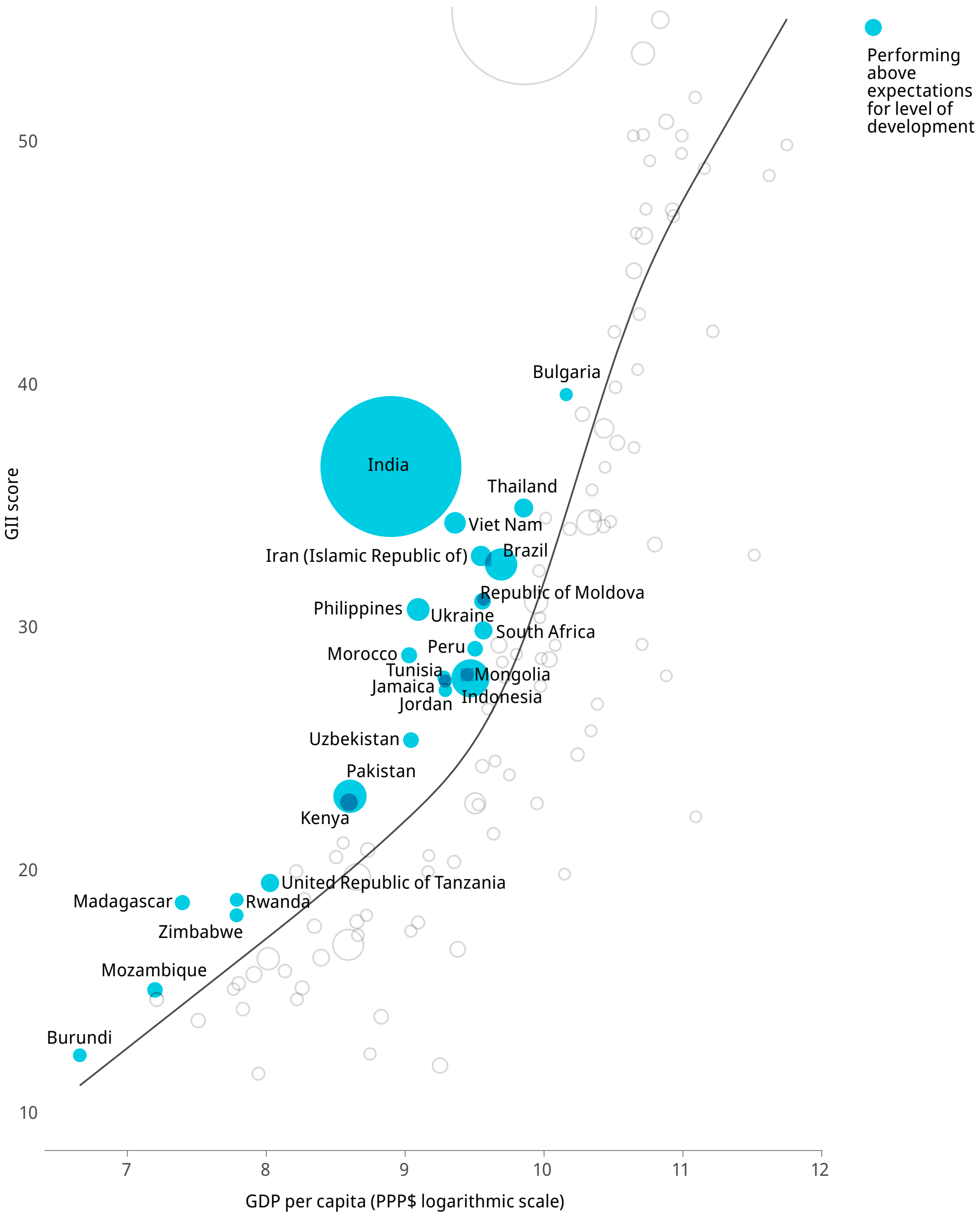
However, there is change too this year. Indonesia (75th), Uzbekistan (82nd) and Pakistan (87th) are Innovation Achievers in 2022 for the first time ever. For these three economies, this achievement coincides with an important shift in their rankings of between four and 12 positions. In addition, Jamaica (76th), Jordan (78th), Zimbabwe (107th), Mozambique (123rd) and Burundi (130th) all make it back into the select group of Innovation Achievers for 2022. Brazil (54th), the Islamic Republic of Iran (53rd) and Peru (65th) keep their achiever status for a second consecutive year. These three economies also gain between three and seven positions in the rankings, with Brazil moving forward since 2019. In 2022, Brazil makes marked improvements in innovation outputs, notably in Creative outputs, including in Intangible assets and Online creativity, as well as in the indicators Trademarks (19th) and Mobile app creation (34th).

Sub-Saharan Africa is the region with the greatest number of economies performing above expectation (eight in total). South East Asia, East Asia, and Oceania is 2nd (with five economies), Central and Southern Asia follow at 3rd (4 economies); and Europe, Northern Africa and Western Asia, and Latin America and the Caribbean tie at 4th (three economies each).

Conversely, 41 economies performed below expectation on innovation. Four are the European Union economies Lithuania (39th), Greece (44th), Slovakia (46th) and Romania (49th). In the upper middle-income group, six are the Latin American and Caribbean economies – Argentina (69th, despite it gaining 4 ranks this year), Panama (81st), the Dominican Republic (90th), Paraguay (91st), Ecuador (98th) and Guatemala (110th). In the lower middle-income group, 14 economies performed below expectation for their level of development, including the Sub-Saharan African economies Côte d'Ivoire (109th), Nigeria (114th), Zambia (118th), Cameroon (121st), Benin (124th), Angola (127th) and Mauritania (129th).

Relative to 2021, 27 economies switched performance groups. Four economies raised their performance status from below expectation to matching expectation, namely, Sri Lanka (85th), Bangladesh (102nd), Ethiopia (117th) and Yemen (128th). Conversely, 12 economies fell back from matching expectation to come below expectation, half of them the Latin America and Caribbean economies of Uruguay (64th), Paraguay (91st), Ecuador (98th), El Salvador (100th), Guatemala (110th) and Honduras (113th).

Figure 11 **The positive relationship between innovation and development**



Source: Global Innovation Index Database, WIPO, 2022.

Note: Bubbles sized by population. The cubic spline trendline shows the expected levels of innovation performance at different levels of GDP per capita for all economies covered in the GII 2022.

Table 3 Innovation Achievers in 2022: Income group, region and years as an innovation achiever

Economy	Income group	Region	Years as an innovation achiever (total)
India	Lower middle-income	Central and Southern Asia	2011–2022 (12)
Kenya	Lower middle-income	Sub-Saharan Africa	2011–2022 (12)
Republic of Moldova	Upper middle-income	Europe	2011–2022 (12)
Viet Nam	Lower middle-income	South East Asia, East Asia, and Oceania	2011–2022 (12)
Mongolia	Lower middle-income	South East Asia, East Asia, and Oceania	2011–2015, 2018–2022 (10)
Rwanda	Low-income	Sub-Saharan Africa	2012, 2014–2022 (10)
Ukraine	Lower middle-income	Europe	2012, 2014–2022 (10)
Mozambique	Low-income	Sub-Saharan Africa	2012, 2014–2020, 2022 (9)
Thailand	Upper middle-income	South East Asia, East Asia, and Oceania	2011, 2014–2015, 2018–2022 (8)
Bulgaria	Upper middle-income	Europe	2015, 2017–2018, 2020–2022 (6)
Madagascar	Low-income	Sub-Saharan Africa	2016–2018, 2020–2022 (6)
Jordan	Upper middle-income	Northern Africa and Western Asia	2011–2015, 2022 (6)
South Africa	Upper middle-income	Sub-Saharan Africa	2018–2022 (5)
Morocco	Lower middle-income	Northern Africa and Western Asia	2015, 2020–2022 (4)
Philippines	Lower middle-income	South East Asia, East Asia, and Oceania	2019, 2020–2022 (4)
Tunisia	Lower middle-income	Northern Africa and Western Asia	2018, 2020–2022 (4)
United Republic of Tanzania	Lower middle-income	Sub-Saharan Africa	2017, 2020–2022 (4)
Burundi	Low-income	Sub-Saharan Africa	2017, 2019, 2022 (3)
Brazil	Upper middle-income	Latin America and the Caribbean	2021–2022 (2)
Iran (Islamic Republic of)	Lower middle-income	Central and Southern Asia	2021–2022 (2)
Peru	Upper middle-income	Latin America and the Caribbean	2021–2022 (2)
Jamaica	Upper middle-income	Latin America and the Caribbean	2020, 2022 (2)
Zimbabwe	Lower middle-income	Sub-Saharan Africa	2012, 2022 (2)
Indonesia	Lower middle-income	South East Asia, East Asia, and Oceania	2022 (1)
Uzbekistan	Lower middle-income	Central and Southern Asia	2022 (1)
Pakistan	Lower middle-income	Central and Southern Asia	2022 (1)

Source: Global Innovation Index Database, WIPO, 2022.

Notes: Income group classification follows the World Bank Income Group Classification (June, 2021). Geographical regions correspond to the United Nations publication on standard country or area codes for statistical use (M49).

The persistent regional innovation divide

South East Asia, East Asia, and Oceania continues to narrow the gap with Northern America and Europe

For another year, there are no changes to how the world regions rank in innovation performance. Northern America and Europe continue to lead, followed by South East Asia, East Asia, and Oceania, and, more distantly, by Northern Africa and Western Asia, Latin America and the Caribbean, Central and Southern Asia, and Sub-Saharan Africa, respectively.[1]

Northern America

Northern America, composed of the United States and Canada, is the most innovative world region. Both economies gained one position this year in the global rankings, reaching the 2nd and 15th places, respectively. This region is the best performer in every GII pillar relative to all other world regions. The United States performs best in Market sophistication (1st worldwide), Business sophistication (3rd) and Knowledge and technology outputs (3rd).

Canada makes a comeback into the top 15, achieving its best rank (15th) since 2016, after having exited the top 10 in 2012. It scores best in indicators Venture capital recipients (1st), Joint venture/strategic alliances (1st) and computer Software spending (3rd).

Europe

Europe still hosts the largest number of innovation leaders – 15 in total – that rank among the top 25. Out of the 39 European economies covered, 12 move up the rankings this year: the Netherlands (5th), Germany (8th), Austria (17th), Estonia (18th), Luxembourg (19th), Malta (21st), Italy (28th), Spain (29th), Poland (38th), Greece (44th), the Republic of Moldova (56th) and Bosnia and Herzegovina (70th).

Switzerland has the most high-performing Institutions in the region (2nd worldwide), and is the regional and global leader in innovation outputs, ranking 1st in both Knowledge and technology outputs and Creative outputs. Germany leads in Human capital and research (2nd), while Sweden comes top in Infrastructure and Business sophistication worldwide (1st in both pillars).

Estonia (18th) heads the region in Market sophistication (3rd), and scores a global leading performance for the indicators E-participation (1st), Venture capital deals (1st), ICT services imports (1st), New businesses (1st), Government's online service (2nd), Entrepreneurship policies and culture (3rd), Mobile app creation (6th), Finance for startups and scaleups (7th) and Environmental performance (14th).

South East Asia, East Asia, and Oceania

The South East Asia, East Asia, and Oceania (SEAO) region continues to close the innovation performance gap with Northern America and Europe. Seven SEAO economies are world innovation leaders: the Republic of Korea (6th), Singapore (7th), China (11th), Japan (13th), Hong Kong, China (14th), New Zealand (24th) and Australia (25th). Singapore, China and New Zealand improved their rankings this year. Among the regional leaders, China, the Republic of Korea and Japan have made the greatest advances up the rankings over the past 10 years. The Republic of Korea held the 21st position in 2012, joined the top 10 in 2020 and moved further ahead to 6th position in 2022. Japan has moved from 25th position in 2012 to be within the vicinity of the top 10, this year retaining 13th place. China held the 34th position in 2012; it joined the innovation leaders in 2016, and has since steadily gained in the rankings every year until this year, in 2022, it is edging the top 10 at 11th place.

Within the region as a whole, Viet Nam (48th), the Philippines (59th), Indonesia (75th), Cambodia (97th) and the Lao People's Democratic Republic (112th) have made the greatest advances over the past decade, moving up more than 20 ranks. These economies continue to lead in key innovation indicators, too. Viet Nam ranks 1st worldwide in High-tech imports, the Philippines is 2nd in High-tech exports, and Indonesia holds 2nd position worldwide in Entrepreneurship policies and culture.

Indonesia (75th) makes a big leap, achieving its best position since 2012, when it ranked 100th. This year, it has made notable improvements in Innovation linkages and in Intangible assets, performing well in indicators such as Finance for startups and scaleups (4th), State of cluster development (9th), University–industry R&D collaboration (13th), and corporate Intangible asset intensity (13th).

Central and Southern Asia

Within Central and Southern Asia, India continues to lead in 40th position, moving further up the rankings, from its 46th position in 2021, and its 81st rank in 2015. The Islamic Republic of Iran is 2nd in the region once again, climbing to 53rd place, improving notably from the 104th place it held back in 2012 and establishing itself as a middle-income economy with the potential to transform the global innovation landscape. Uzbekistan rises to 3rd in the region, ranking 82nd overall, and displacing Kazakhstan to 4th in the region and the 83rd position globally.

Sri Lanka (85th), Pakistan (87th) and Bangladesh (102nd) jumped up the rankings notably this year. However, only Pakistan has steadily gained position over time (it ranked 133rd in 2012), whereas Sri Lanka has gone up and down the rankings, this year reclaiming the 85th position it first held back in 2015. Bangladesh improves this year, notably in Creative outputs, Intangible assets and Online creativity, performing especially well in corporate Intangible asset intensity (26th).

Northern Africa and Western Asia

Within Northern Africa and Western Asia, Israel (16th) continues far in advance of the region as a whole and in a consistent manner. It has been an innovation leader for the past 15 years. Israel leads the region in Market sophistication (7th), Business sophistication (6th), and Knowledge and technology outputs (7th). It is a world leader in the indicators Venture capital deals, Females employed with advanced degrees, PCT patents and ICT services exports, ranking 1st worldwide for each (see Box 1). Israel is also the only country that spends more than 5 percent of GDP on R&D, reaching 5.4 percent in 2020.

The United Arab Emirates (UAE) takes a big leap forward this year reaching 31st place, bringing it closer to the top 30. Türkiye makes it into the top 40, taking 37th spot. Türkiye tops the region in Creative outputs (15th) and ranks 4th worldwide in Intangible assets, becoming a global leader in the indicators Industrial designs (1st), Trademarks (6th), and Intangible asset intensity (15th). Given its recent performance, as middle-income economy, Türkiye has the potential to undergo innovation performance growth similar to that of China in future years.

An additional 10 economies within the region move up the rankings, including notable improvers Saudi Arabia (51st), Qatar (52nd), Kuwait (62nd), Morocco (67th) and Bahrain (72nd).

Table 4 Heatmap: GII 2022 rankings overall and by innovation pillar

Country/economy	Overall GII	Institutions	Human capital and research	Infrastructure	Market sophistication	Business sophistication	Knowledge and technology outputs	Creative outputs
Switzerland	1	2	4	4	8	7	1	1
United States	2	13	9	19	1	3	3	12
Sweden	3	19	3	1	13	1	2	8
United Kingdom	4	24	6	8	5	22	8	3
Netherlands	5	4	14	14	18	10	5	10
Republic of Korea	6	31	1	13	21	9	10	4
Singapore	7	1	7	11	4	2	13	21
Germany	8	20	2	23	14	19	9	7
Finland	9	11	8	3	17	5	4	18
Denmark	10	9	10	5	15	15	12	14
China	11	42	20	25	12	12	6	11
France	12	18	15	17	10	17	15	6
Japan	13	21	21	12	9	8	11	19
Hong Kong, China	14	10	13	6	2	27	60	5
Canada	15	15	12	30	6	20	24	20
Israel	16	41	24	42	7	6	7	36
Austria	17	8	11	9	38	18	19	26
Estonia	18	12	34	10	3	25	21	24
Luxembourg	19	5	32	40	31	4	33	9
Iceland	20	14	29	22	41	14	22	13
Malta	21	28	42	27	33	16	32	2
Norway	22	3	19	2	28	21	25	30
Ireland	23	16	23	15	55	13	14	29
New Zealand	24	7	18	21	24	31	29	22
Australia	25	17	5	18	20	24	37	27
Belgium	26	29	16	37	45	11	18	32
Cyprus	27	36	39	28	29	23	20	17
Italy	28	58	28	26	35	33	16	16
Spain	29	38	26	16	30	32	27	28
Czech Republic	30	43	33	20	76	28	17	37
United Arab Emirates	31	6	17	7	23	26	59	45
Portugal	32	47	22	39	42	34	35	25
Slovenia	33	37	25	24	68	29	26	56
Hungary	34	48	37	35	67	30	23	46
Bulgaria	35	67	68	34	62	40	30	23
Malaysia	36	34	38	51	26	41	39	41
Türkiye	37	101	41	48	37	47	47	15
Poland	38	65	36	43	61	38	38	38
Lithuania	39	26	44	45	32	37	48	47
India	40	54	43	78	19	54	34	52
Latvia	41	35	48	52	65	36	44	42
Croatia	42	77	46	31	56	46	45	39
Thailand	43	78	71	54	27	43	43	49
Greece	44	69	31	46	64	55	46	54
Mauritius	45	22	66	70	16	96	82	31
Slovakia	46	68	59	41	70	45	28	70
Russian Federation	47	89	27	62	48	44	51	48
Viet Nam	48	51	80	71	43	50	52	35
Romania	49	75	74	33	63	51	31	57
Chile	50	39	57	47	46	57	54	55
Saudi Arabia	51	50	30	53	22	53	65	66
Qatar	52	25	56	29	47	73	69	59
Iran (Islamic Republic of)	53	131	54	75	11	115	50	33
Brazil	54	102	50	65	49	35	55	51
Serbia	55	53	52	38	83	65	42	76
Republic of Moldova	56	98	62	84	58	79	49	43
Ukraine	57	97	49	82	102	48	36	63
Mexico	58	93	58	63	54	76	58	50
Philippines	59	90	86	81	78	39	41	58
Montenegro	60	59	61	44	53	58	72	71
South Africa	61	81	81	77	39	63	56	64
Kuwait	62	86	55	36	73	101	68	60
Colombia	63	72	79	59	66	42	67	75
Uruguay	64	32	73	60	77	62	62	85
Peru	65	61	47	79	40	49	90	65
North Macedonia	66	88	75	49	34	59	57	93

4th quartile (best performers, ranks 1st to 33rd) 3rd quartile (ranks 34th to 66th) 2nd quartile (ranks 67th to 99th) 1st quartile (ranks 100th to 132nd)

Table 4 Continued

Country/economy	Overall GII	Institutions	Human capital and research	Infrastructure	Market sophistication	Business sophistication	Knowledge and technology outputs	Creative outputs
Morocco	67	85	83	89	74	94	64	44
Costa Rica	68	44	77	66	88	60	61	81
Argentina	69	96	69	64	95	52	77	53
Bosnia and Herzegovina	70	94	67	55	25	98	63	83
Mongolia	71	76	64	92	97	61	85	40
Bahrain	72	27	78	32	75	93	73	98
Tunisia	73	92	45	85	98	116	53	61
Georgia	74	30	70	83	72	64	75	86
Indonesia	75	71	90	68	36	92	78	72
Jamaica	76	56	84	99	110	67	89	34
Belarus	77	130	35	67	96	72	40	91
Jordan	78	45	76	100	52	75	76	78
Oman	79	57	40	56	71	97	94	80
Armenia	80	55	91	80	85	84	71	73
Panama	81	70	94	50	89	105	86	62
Uzbekistan	82	63	65	74	60	74	80	102
Kazakhstan	83	52	60	58	90	68	81	118
Albania	84	84	89	57	91	56	96	82
Sri Lanka	85	119	120	73	108	71	66	69
Botswana	86	40	51	88	112	70	88	100
Pakistan	87	118	113	114	100	81	70	67
Kenya	88	82	119	107	111	80	74	79
Egypt	89	111	97	93	86	103	79	84
Dominican Republic	90	80	108	69	84	83	93	88
Paraguay	91	115	100	76	82	86	105	74
Brunei Darussalam	92	23	53	61	101	66	127	125
Azerbaijan	93	46	87	90	80	77	117	105
Kyrgyzstan	94	113	63	86	51	107	92	121
Ghana	95	100	101	96	119	88	103	77
Namibia	96	49	72	106	81	108	113	113
Cambodia	97	87	99	103	44	117	101	104
Ecuador	98	121	98	72	103	85	102	96
Senegal	99	60	103	105	69	124	97	112
El Salvador	100	107	107	97	99	87	108	90
Trinidad and Tobago	101	66	88	87	123	102	87	117
Bangladesh	102	109	127	94	92	125	95	87
United Republic of Tanzania	103	74	126	104	79	112	114	94
Tajikistan	104	91	85	121	94	128	84	116
Rwanda	105	33	106	95	115	113	111	126
Madagascar	106	120	105	132	109	118	115	68
Zimbabwe	107	128	92	126	114	90	99	89
Nicaragua	108	124	110	111	50	82	121	103
Côte d'Ivoire	109	73	122	98	122	95	104	108
Guatemala	110	122	121	119	107	89	91	99
Nepal	111	117	123	108	59	91	119	101
Lao People's Democratic Republic	112	103	111	118	57	104	122	114
Honduras	113	125	96	101	104	78	110	120
Nigeria	114	112	109	112	126	69	123	97
Algeria	115	99	82	102	125	120	118	109
Myanmar	116	123	102	128	93	130	100	106
Ethiopia	117	110	131	123	113	122	83	115
Zambia	118	126	118	116	106	100	116	110
Uganda	119	62	129	109	127	126	106	123
Burkina Faso	120	105	104	115	118	123	112	127
Cameroon	121	104	116	113	132	99	98	124
Togo	122	108	117	117	105	129	126	111
Mozambique	123	129	114	91	120	121	120	107
Benin	124	64	115	110	117	114	129	132
Niger	125	79	130	129	116	106	109	131
Mali	126	114	128	125	124	110	107	122
Angola	127	116	125	122	121	131	130	92
Yemen	128	132	124	120	87	127	124	95
Mauritania	129	83	112	127	129	111	132	130
Burundi	130	106	95	130	130	119	128	128
Iraq	131	127	93	124	128	132	125	129
Guinea	132	95	132	131	131	109	131	119

4th quartile (best performers, ranks 1st to 33rd) | 3rd quartile (ranks 34th to 66th) | 2nd quartile (ranks 67th to 99th) | 1st quartile (ranks 100th to 132nd)

Source: Global Innovation Index Database, WIPO, 2022.

Latin America and the Caribbean

Within Latin America and the Caribbean, Chile (50th) re-enters the top 50, while Brazil continues to move forward at 54th spot. Mexico remains within the top 60 at 58th position, but drops three ranks from last year, its lowest position since 2017. Eight out of the 18 economies covered within the region go up the rankings, but in a relatively modest manner compared to other world regions, with Colombia (63rd), Peru (65th) and Argentina (69th) recording the most notable increases, and all making it into the top 70. Over the past decade, only Mexico, Peru and Jamaica (76th) have gained more than 10 ranks, while Brazil and Argentina have experienced a more accelerated ranking increase over the past five years.

Uruguay is the regional leader in Institutions (32nd), Peru leads in Human capital and research (47th) and Market sophistication (40th), and Chile in Infrastructure (47th) and Knowledge and technology outputs (54th). Brazil is top of the region for Business sophistication (35th).

Among Caribbean economies, only the Dominican Republic climbs the rankings to 90th position – although it continues to perform below expectation for its level of development. In 2022, Jamaica ranks best in the region in terms of Creative outputs (34th), including in indicators such as Trademarks (9th) and Industrial designs (14th).

This year, Peru, Brazil and Jamaica also performed on innovation above expectation for their level of development (Table 3). Conversely, six Latin American and Caribbean economies have declined in performance status, no longer meeting expectation but instead performing below expectation for their level of development, pointing to a possible innovation performance stagnation within the region.

Sub-Saharan Africa

In Sub-Saharan Africa, only Mauritius (45th) and South Africa (61st) rank among the top 80. Five of the region's other economies rank within the top 100 this year: Botswana (86th), Kenya (88th), Ghana (95th), Namibia (96th) and Senegal (99th) (Table 5). Sixteen economies move up the GII rankings, with Mauritius, Botswana, Ghana, Senegal, Zimbabwe (107th), Ethiopia (117th) and Angola (127th) making noteworthy improvements. Burundi (130th) makes a return to the GII this year thanks to improved data availability, after having held 128th position in the GII in 2019. Mauritania joins the GII for the first time at 129th place.

Mauritius ranks highest within the region in Institutions (22nd), Infrastructure (70th), Market sophistication (16th), and Creative outputs (31st). It leads worldwide in Venture capital deals (1st), and performs notably well in Trademarks (15th), ICT services imports (20th) and New businesses (20th). Botswana tops in Human capital and research (51st), and performs well in indicators such as Expenditure on education (2nd), New businesses (4th), Loans from microfinance institutions (15th) and Intellectual property payments (22nd). Namibia leads worldwide in Expenditure on education (1st) and performs well above the regional average on Human capital and research. South Africa heads the region in Business sophistication (63rd) and Knowledge and technology outputs (56th).

Table 5 GII 2022 rankings in Sub-Saharan Africa

Rank	Top 80	Rank	Top 100	Rank	Top 110	Rank	Top 120	Rank	Other
45	Mauritius	86	Botswana	103	United Republic of Tanzania	114	Nigeria	121	Cameroon
61	South Africa	88	Kenya	105	Rwanda	117	Ethiopia	122	Togo
		95	Ghana	106	Madagascar	118	Zambia	123	Mozambique
		96	Namibia	107	Zimbabwe	119	Uganda	124	Benin
		99	Senegal	109	Côte d'Ivoire	120	Burkina Faso	125	Niger
								126	Mali
								127	Angola
								129	Mauritania
								130	Burundi
								132	Guinea

Source: Global Innovation Index Database, WIPO, 2022.

Creating balanced and efficient innovation ecosystems

Several economies are still struggling to translate innovation inputs into outputs efficiently

Some economies are very efficient at converting innovation inputs into outputs. Among the high-income group, Switzerland (1st) produces considerably higher levels of outputs than other high-income economies, such as the United States (2nd), Sweden (3rd) and Singapore (7th), at comparable levels of innovation inputs (Figure 12). Germany (8th) produces the same levels of outputs as the United States and the Netherlands (5th), at lower levels of innovation inputs.

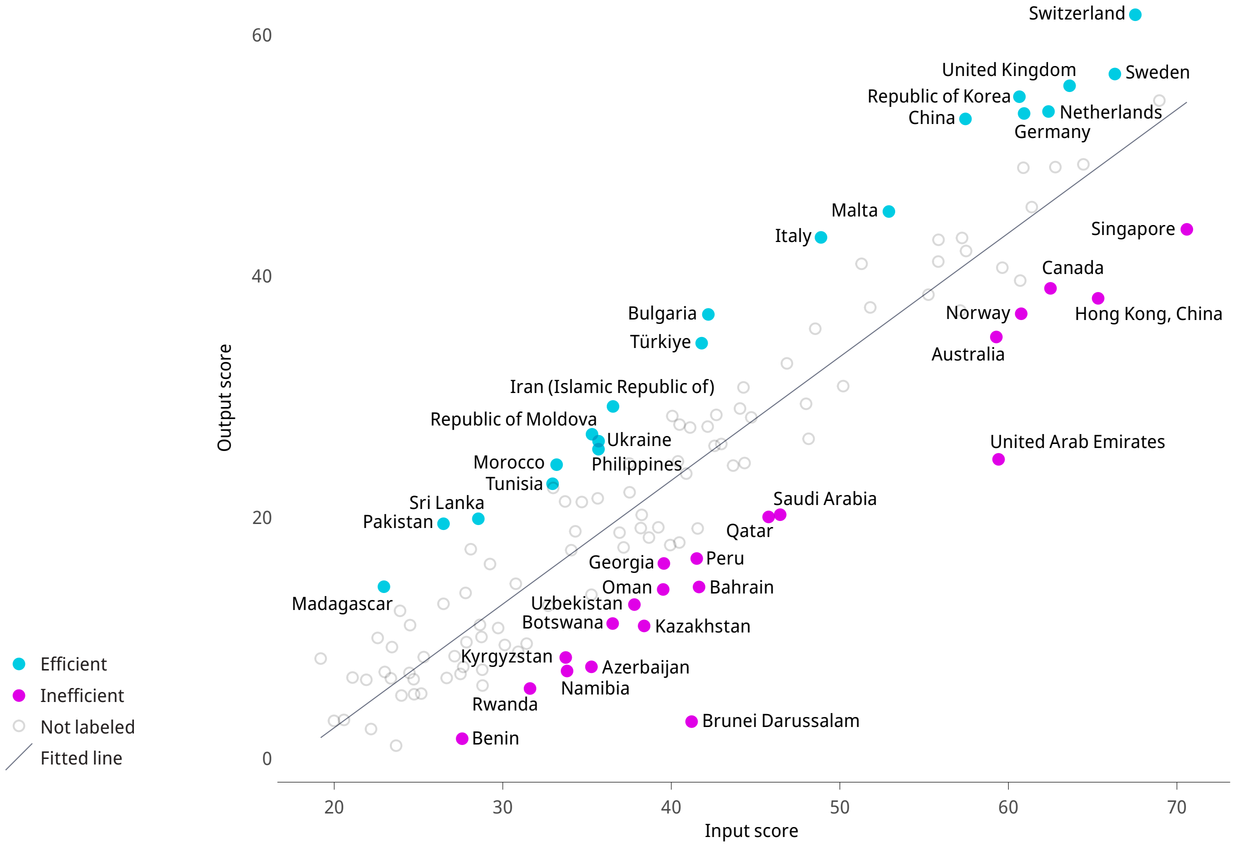
Among upper middle-income group economies, China (11th) ranks 8th overall in the Innovation Output Sub-Index, and its levels of outputs are comparable to those of high-income economies like the Netherlands and Germany, but at lower levels of innovation inputs. Türkiye (37th) has outputs comparable to high-income economies, such as Australia (25th), but with fewer inputs.

The Islamic Republic of Iran (53rd), among lower middle-income group economies, performs on innovation outputs at levels comparable to high-income European economies Latvia (41st) and Croatia (42nd). In addition, the Philippines (59th) does likewise, relative to Lithuania (39th) and Greece (44th), with a lower level of innovation inputs.

However, several high-income economies struggle to obtain a better balance between level of investment and results, often to the detriment of their overall innovation performance. This group of economies includes, notably, oil and natural gas producers and exporters Canada (15th), Norway (22nd), the United Arab Emirates (31st), Saudi Arabia (51st), Bahrain (72nd) and Brunei Darussalam (92nd). Other economies struggling to translate inputs into outputs include Singapore (7th), Australia (25th), Uzbekistan (82nd) and Rwanda (105th).

Among the top 25 (innovation leaders), Canada has managed to tilt the balance in its favor this year by becoming more productive in converting innovation inputs into outputs, making a comeback into the GII top 15.

Figure 12 Innovation input to output performance, 2022



Source: Global Innovation Index Database, WIPO, 2022.

A balanced and strong performance across all seven innovation pillars is most evident among the innovation leaders (top 25), but particularly the top 10. Only 15 economies in total – including Norway and New Zealand who are not in the GII top 20 – perform strongly across all seven GII pillars (Table 4).

However, certain economies ranked lower overall in the GII are nevertheless leaders in specific areas. Examples include Uruguay (32nd) and Rwanda (33rd) ranked highly for the quality of their Institutions; Bahrain (32nd) for its Infrastructure; and the Islamic Republic of Iran (11th), India (19th) and Malaysia (26th) for their Market sophistication. In addition, Slovakia (28th) and Romania (31st) score highly in Knowledge and technology outputs, and Türkiye (15th) in Creative outputs. Such imbalances in performance within economies hints at innovation systems that are changing, dynamic and have the potential for increased overall performance in the future.

Box 2 describes the process involved in using the GII to improve an economy's innovation performance.

Box 2 **What is the recipe for improving an economy's innovation performance as measured by the GII?**

For many years, governments around the world have used the GII to improve their innovation performance and shape evidence-based innovation policies. Every year since the GII first launched, numerous GII workshops and missions have taken place in collaboration with a number of different economies around the world – often in the presence of key ministers, ministries and innovation actors.

A survey carried out by WIPO in early 2022 shows that 70 percent of WIPO member states use the Global Innovation Index (GII). Out of the 110 responses received (one response per country), 68 countries had used the GII during the period 2020–2021 to improve their innovation ecosystems and policymaking, while 37 went so far as to use the GII as a specific reference in economic plans or policies.

While there is no recipe for moving up the GII rankings, this box discusses the process of using the GII to improve an economy's innovation performance.

A chief benefit of the GII is that it puts data-based evidence and metrics at the core of evaluating, crafting and deploying innovation policies. As a first step, countries begin by bringing together statisticians and decision-makers in order to understand the country's innovation performance, based on the GII metrics. In a second step, the policy discussion turns to leveraging domestic innovation opportunities, while at the same time overcoming country-specific weaknesses. Both steps are an exercise in careful coordination among different public and private innovation actors, as well as between government entities at the local, regional and national levels. Ideally, the GII becomes a tool for such coordination.

Some do's:

- Ensure innovation is embedded as a key priority in the country's pathway to national development and progress, possibly formulated within a clear innovation policy.
- Establish a cross-ministerial task force to pursue innovation policy and GII matters through a "whole of government approach," ideally reporting to the top tier of government, for instance, the Prime Minister's Office.
- Ensure any innovation policy task force interacts and consults with innovation actors from both the private and public sectors, including start-ups, deans of research universities and relevant innovation clusters.
- Ensure any national intellectual property (IP) policy is aligned with or even integrated into the above innovation policy.
- Ensure the targets or actions of innovation policy are quantifiable, and that they are regularly revisited and evaluated.

Some don'ts:

- Do not set over-ambitious and therefore unrealistic GII ranking targets – for example, by aiming to enter the top 20 by next year when the economy's ranking would suggest it is still far from achieving that goal. GII rankings rarely increase in large leaps from one year to the next, particularly at the top.
- Do not expect policy changes to result in improved GII indicator performance instantaneously. There are important lags between innovation policy formulation, execution and impact. The latest available innovation data is also rarely current, often lagging by a few years.

- Do not treat the GII as a mathematical exercise – that is, by attempting to collect or focus on specific indicators in order to climb the rankings. GII rank alone is only a partial reflection of national development and progress.
- Do not over focus on year-on-year changes to the GII alone. These are influenced by relative performance vis-à-vis other countries and other methodological considerations (see Appendix I), many of which lie outside the control of the economy in question. Setting objectives over a multi-year period – for example, three to five years – and looking at combined progress over several years is a more fitting use of the GII.

Conclusion

The aim of the GII is to provide insightful data on innovation, to track major innovation developments at the country and regional level and, in turn, to assist policymakers in evaluating their innovation performance and making informed innovation policy decisions.

The GII is not intended to be considered as representing the ultimate and definitive ranking of economies with respect to innovation. On the contrary, the GII best represents an ongoing endeavor to find metrics and approaches that capture the richness of innovation most effectively, with continuous refinements reflecting an improved availability of statistics and theoretical advances in the field, and paving the way for the adoption of better and more informed innovation policies worldwide.

Several key insights emerge from this year's GII report.

- The global innovation landscape is changing – both within the top 25 leading innovation economies, as well as more generally within the overall rankings and the league tables by income group or region. The most notable of these changes are: (i) a significant shift within this year's top 15 innovators, with the United States, Singapore, Germany and China moving up the ranking, the latter overtaking France, and with Canada moving back into the top 15 thanks to improved innovation efficiency; (ii) the continued strong progression of emerging innovation powerhouses Türkiye, India and to some extent the Islamic Republic of Iran, while that of Viet Nam and the Philippines has halted momentarily; and (iii) the early signs of innovation potential coming from Indonesia, Uzbekistan and Pakistan, which all overperformed on innovation performance relative to development for the first time in 2022.
- Despite such shifts, and despite the fact that Asia as a region is catching up rapidly on Northern America and Europe, the gap with other world regions, notably Latin America and the Caribbean and Sub-Saharan Africa, needs urgent attention. Importantly, the short and longer-term impacts of the COVID-19 pandemic, the current geopolitical turmoil, the tightening of monetary policies, and the repercussions of shocks to global supply chains and global innovation networks on nascent innovation systems in middle- and low-income economies all need close monitoring. The last two decades achieved great things in terms of putting innovation systems and innovation policies on the agenda of developing countries' policymakers, legislators and innovation actors. It would be a great shame were this attention, together with the accrued political will and experience, to come under threat due to ongoing crises.

Future editions of the GII will track developments closely and continue the journey toward enabling policy and business leaders through the fostering of a better understanding and measurement of innovation.

Note

1 The regional rankings correspond to the average unweighted scores of a region's economies.

Cluster ranking

The GII reveals the world's top 100 science and technology (S&T) clusters and identifies the most S&T-intensive top global clusters.

The GII 2022 top 100 science and technology clusters

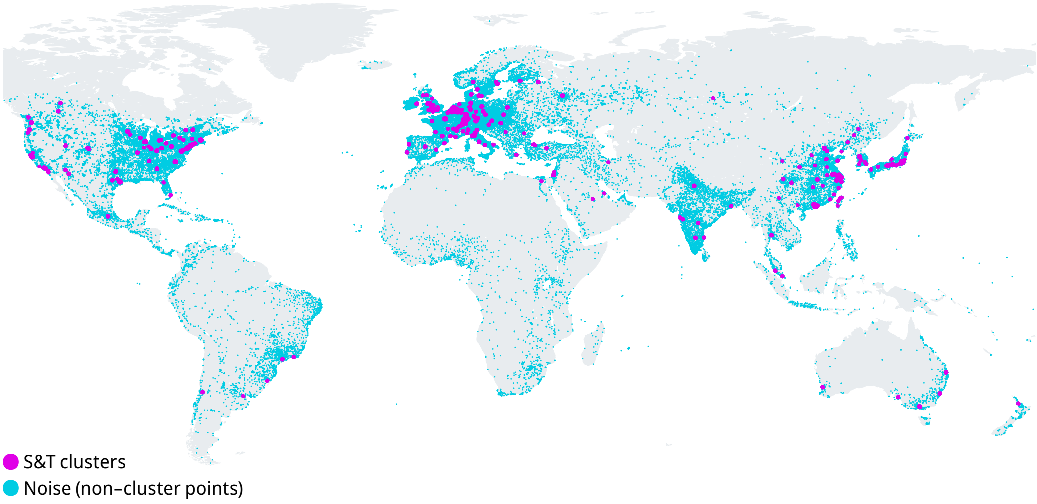
Recognizing that innovation output at the local level is as important as output at the national level, the Global Innovation Index (GII) continues to present the world's largest top 100 science and technology (S&T) clusters (see Map 1) – that is, the geographical areas around the world with the highest density of inventors and scientific authors (see Appendix IV, which details the methodological adjustment employed).

For the first time, this year the GII also presents S&T clusters beyond the top 100, shedding light on those clusters not normally highlighted in the section.

Tokyo–Yokohama continues to lead the top 100 S&T clusters

Among the top 100, Tokyo–Yokohama (Japan) is the top-performing cluster, followed by Shenzhen–Hong Kong–Guangzhou (China and Hong Kong, China), Beijing (China), Seoul (Republic of Korea) and San Jose–San Francisco (United States) (see Appendix Table 3).
The top 10 clusters remain the same as last year, with one difference: Shanghai and Suzhou have now merged into one cluster.

Map 1 Top 100 clusters worldwide, 2022



Source: WIPO Statistics Database, April 2022.
Note: Noise refers to all inventor/author locations not classified in a cluster.

The largest increases in the ranking came from three Chinese clusters – Zhengzhou (+15 positions), Qingdao (+12) and Xiamen (+12). Berlin (+4) in Germany, Istanbul (+4) in Türkiye, Kanazawa (+4) in Japan, Ankara (+3) in Türkiye, Daegu (+3) in the Republic of Korea and Mumbai (+3) in India also advanced strongly this year.

Chinese clusters experienced the largest increases in S&T output too, with the median increase equating to +13.9 percent and with China hosting the fastest growing clusters – Qingdao (+25.2 percent) and Wuhan (+21.9 percent).[1] Other clusters in middle-income economies, besides those in China, also experienced strong growth, including Istanbul (Türkiye, +7.3 percent), Chennai (India, +7.1 percent) and Delhi (India, +5.2 percent).

High-income economy clusters generally grew at a slower pace than clusters in middle-income economies. However, there were some notable exceptions among the high-income economy clusters, namely Basel (+10.5 percent), a new top 100 entrant this year from the French, German and Swiss border region, Munich (+8.6 percent) in Germany – closing the gap between it and Cologne – and Kanazawa (+8.1 percent) in Japan.

The top S&T clusters of each economy or cross-border region are shown in Table 6.

Table 6 Top S&T cluster of each economy or cross-border region, rank among the top 100, 2022

Rank	Cluster name	Economy	Rank change since 2021
1	Tokyo–Yokohama	JP	0
2	Shenzhen–Hong Kong–Guangzhou	CN/HK	0
3	Beijing	CN	0
4	Seoul	KR	0
5	San Jose–San Francisco, CA	US	0
10	Paris	FR	0
19	London	GB	0
23	Cologne	DE	−2
25	Amsterdam–Rotterdam	NL	−2
26	Taipei–Hsinchu	TW*	0
30	Tel Aviv–Jerusalem	IL	−2
31	Moscow	RU	−1
32	Tehran	IR	0
33	Singapore	SG	−2
35	Stockholm	SE	0
36	Eindhoven	NL/BE	−2
39	Melbourne	AU	−2
46	Istanbul	TR	4
47	Brussels	BE	−4
48	Madrid	ES	−1
51	Zürich	CH/DE	1
53	Milan	IT	0
54	Toronto, ON	CA	−5
59	Copenhagen	DK	−4
60	Bengaluru	IN	0
71	São Paulo	BR	0
73	Helsinki	FI	−1
76	Vienna	AT	−1
92	Warsaw	PL	0
93	Lausanne	CH/FR	−3
99	Basel	CH/DE/FR	7

Source: WIPO Statistics Database, April 2022.

Notes: The codes given in the tables in this section are the ISO alpha-2 country codes, with the following addition: *TW = Taiwan, Province of China.

China is now on a par with the United States in terms of the number of top 100 S&T clusters

In 2022, as in previous years, the top 100 S&T clusters are highly concentrated in three regions, Northern America, Europe and Asia and, especially, in two countries: the United States and China (see Map 1).

For the first time, China hosts as many clusters as the United States, with 21 each (see Map 2a and 2b and Table 7). Germany follows, with 10 clusters in the top 100, with Cologne and Munich as the two largest clusters. Japan has five clusters in the top 100, with Tokyo–Yokohama and Osaka–Kobe–Kyoto also represented in the top 10 clusters overall.

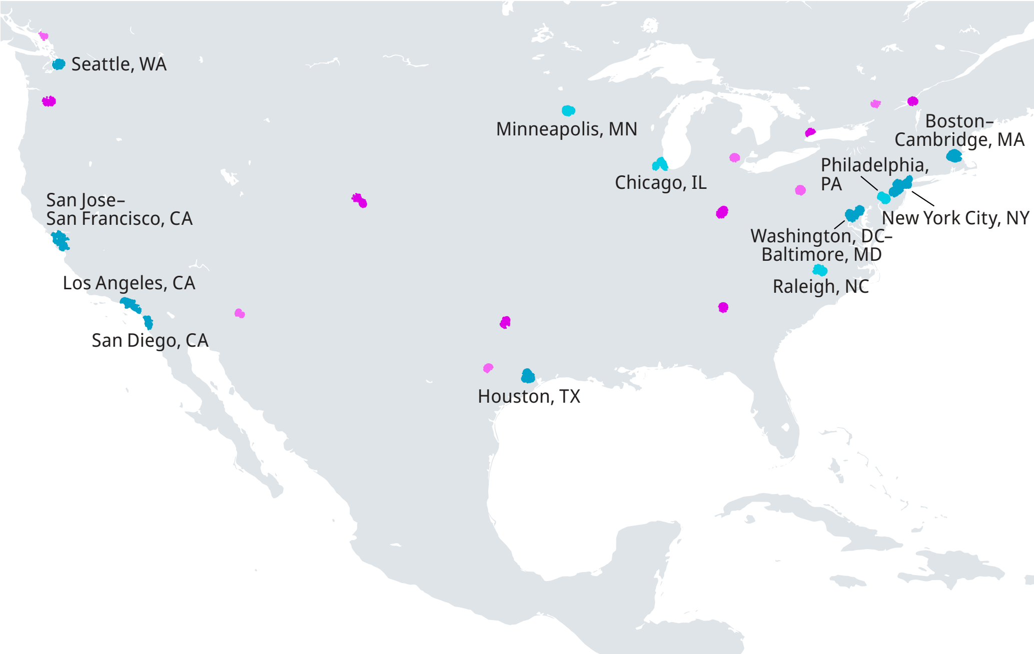
Mirroring last year's results, with the exception of China, only five middle-income economies have clusters in the top 100:

- Brazil (1 cluster), with São Paulo, the sole top 100 S&T cluster in Latin America;
- India (4), with Bengaluru, Delhi and Mumbai, as last year, and Chennai making the top 100 for the first time;
- the Islamic Republic of Iran (1), with Tehran;
- Türkiye (2), with Istanbul and Ankara; and
- the Russian Federation (1), with Moscow.

It is notable that, among the aforementioned clusters, Ankara and Istanbul, the two Turkish clusters, and Mumbai have made significant jumps forward.

Map 2 Top S&T clusters, United States and China, 2022

a – United States and Canada



Cluster rank
- 1–25
- 26–50
- 51–75
- 76–100

b – East Asia

Cluster rank
- 1–25
- 26–50
- 51–75
- 76–100

Source: WIPO Statistics Database, April 2022.

Table 7 Economies with three or more top 100 S&T clusters, 2022

Economy	Economy name	Number of top 100 clusters
US	United States	21
CN	China	21
DE	Germany	10
JP	Japan	5
FR	France	4
CA	Canada	4
IN	India	4
KR	Republic of Korea	4
GB	United Kingdom	3
AU	Australia	3
CH	Switzerland	3
SE	Sweden	3

Source: WIPO Statistics Database, April 2022.

Beyond the top 100: Bangkok, Buenos Aires, Cairo, Kuala Lumpur and Mexico City are top S&T clusters in middle-income economies

Using the same thresholds employed for the identification of top 100 S&T clusters, the GII 2022 also identifies clusters beyond the top 100 without determining their precise ranking.

Based on the same parameters applied to produce the top 100 ranking, 123 additional clusters are identified beyond the top 100, including 23 clusters based in the United States, 13 in both China and Germany and 10 in both France and the United Kingdom.

In India, Kolkata, Pune and Hyderabad stand out. Brazil's Rio de Janeiro and Porto Alegre were also added, along with Saint Petersburg and Novosibirsk in the Russian Federation.

Table 8 identifies top S&T clusters in economies not covered previously in the top 100, including Portugal and Saudi Arabia, with two clusters each. Among the middle-income economies, Argentina, Egypt, Malaysia, Mexico and Thailand each host a top S&T cluster in the extended list, namely Buenos Aires, Cairo, Kuala Lumpur, Mexico City and Bangkok, respectively. Other prominent Latin American urban areas – such as Mexico City, Rio de Janeiro, Porto Alegre and Santiago de Chile – feature in this extended list as well.

Table 8 Top S&T clusters in extended ranking, economies not covered in top 100, 2022

Economy	Economy name	Cluster name
PT	Portugal	Lisbon and Porto
SA	Saudi Arabia	Riyadh and Dammam
AR	Argentina	Buenos Aires
CL	Chile	Santiago
CZ	Czech Republic	Prague
EG	Egypt	Cairo
GR	Greece	Athens
HU	Hungary	Budapest
IE	Ireland	Dublin
MO	Macao, China	Macau
MY	Malaysia	Kuala Lumpur
MX	Mexico	Mexico City
NZ	New Zealand	Auckland
NO	Norway	Oslo
RO	Romania	Bucharest
RS	Serbia	Belgrade
TH	Thailand	Bangkok

Source: WIPO Statistics Database, April 2022.

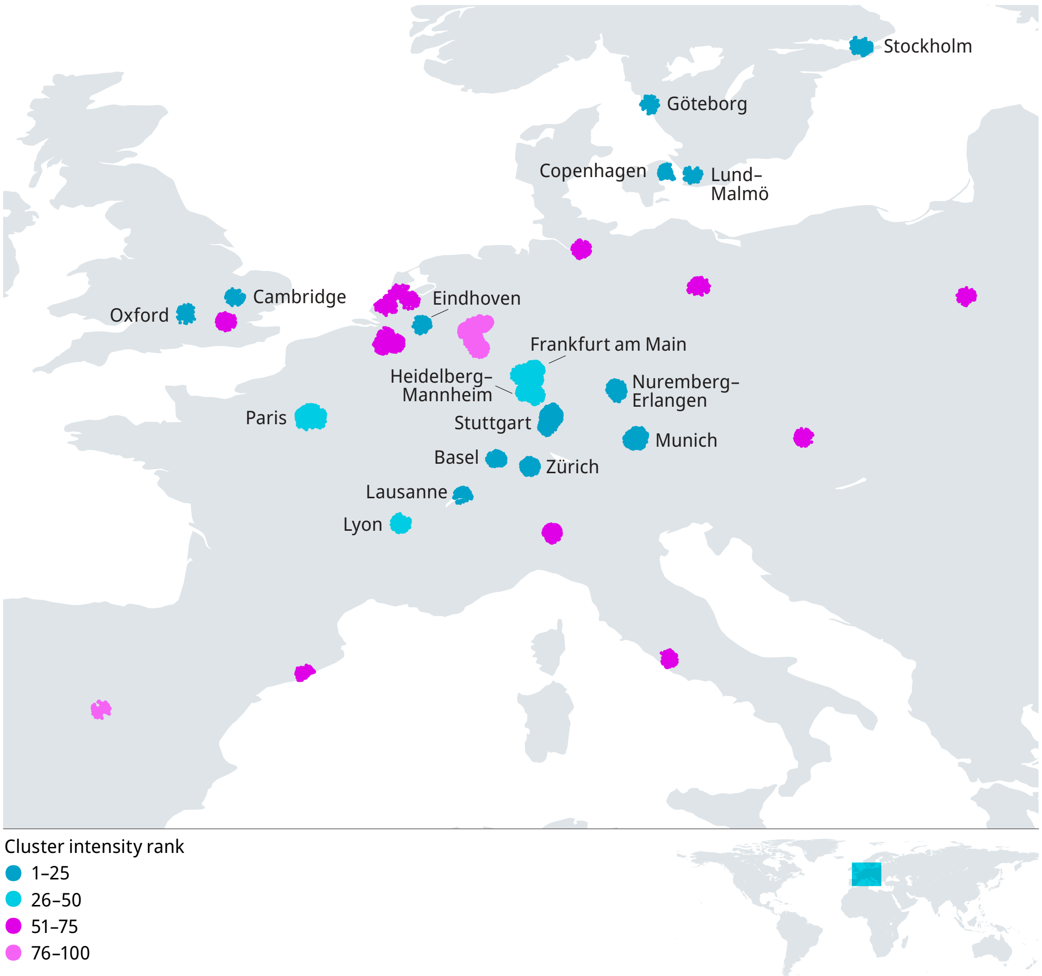
S&T intensity of the top 100 clusters

Since 2020, the GII has also presented the top 100 clusters ranked by their S&T intensity – that is, the sum of their patent and scientific publication shares divided by population. This work draws on geospatial imagery to estimate the underlying population levels (see Appendix IV).

Cambridge in the United Kingdom and Eindhoven in the Netherlands/Belgium are found to be the most S&T-intensive clusters, followed by Daejeon (Republic of Korea), San Jose–San Francisco (United States) and Oxford (United Kingdom) (see Appendix Table 4). Sweden is making a strong showing overall with Lund–Malmö, Stockholm and Göteborg. Only San Jose–San Francisco makes the top five of the GII S&T cluster and the GII S&T intensity ranking.

Through this fresh lens, many European and United States clusters show more intense S&T activity than their Asian counterparts (see Map 3 and Table 9). The United States has seven clusters in the top 25 by S&T intensity, followed by Germany with five, and Switzerland and Sweden with three each.

Map 3 European S&T clusters by intensity



Source: WIPO Statistics Database, April 2022.

Table 9 Top S&T clusters by S&T intensity, 2022

Rank per capita	Cluster name	Economy
1	Cambridge	GB
2	Eindhoven	NL/BE
3	Daejeon	KR
4	San Jose–San Francisco, CA	US
5	Oxford	GB
6	Boston–Cambridge, MA	US
7	Ann Arbor, MI	US
8	San Diego, CA	US
9	Seattle, WA	US
10	Lund–Malmö	SE
11	Lausanne	CH/FR
12	Raleigh, NC	US
13	Munich	DE
14	Kanazawa	JP
15	Stockholm	SE
16	Göteborg	SE
17	Helsinki	FI
18	Nuremberg–Erlangen	DE
19	Zürich	CH/DE
20	Tokyo–Yokohama	JP
21	Copenhagen	DK
22	Beijing	CN
23	Stuttgart	DE
24	Basel	CH/DE/FR
25	Portland, OR	US

Source: WIPO Statistics Database, April 2022.

As was the case in the previous year's GII S&T cluster ranking, S&T intensity was higher in those cases where patenting activity drove a cluster's output, with 20 out of the top 25 clusters deriving the majority of their output from patents.

As expected, China, in particular, scores less well when correcting for population. Applying this methodology, Beijing (23) makes it into the top 25 by S&T intensity but no other Chinese or middle-income economy cluster does. Relative to the top S&T cluster ranking, Brazil, India, Iran, the Russian Federation and Türkiye maintain the same number of clusters in this top 100 S&T intensity ranking: Tehran (77) in Iran; Ankara (91) and Istanbul (95) in Türkiye; Moscow (94) in the Russian Federation; Bengaluru (96), Chennai (97), Delhi (99) and Mumbai (100) in India; and São Paulo (98) in Brazil (in order of best ranked cluster, with Tehran ranking highest).

Note

1 S&T output growth refers to the net S&T output over time, which is the difference in total patents and publications for each cluster, for all points that were located inside the same cluster compared to the previous year.

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?

Klaas de Vries, The Conference Board
Sacha Wunsch-Vincent, World Intellectual Property Organization (WIPO)

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?

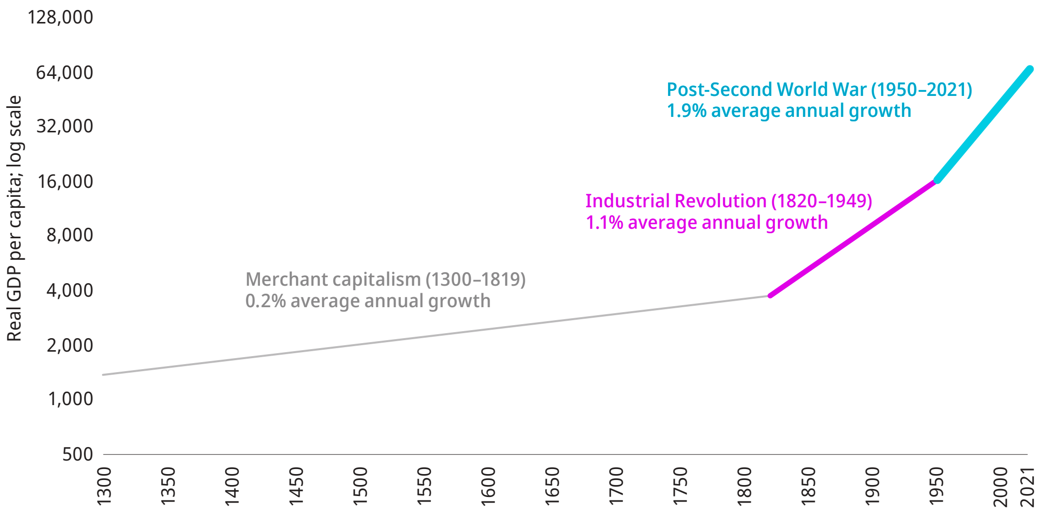
To answer these questions and more, this introduction to the GII 2022 Special theme first assesses the severity of the productivity growth slowdown since the 1970s that continues up to the present day. The main reasons for pessimism about the future of innovation-driven growth are laid out, but also 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.

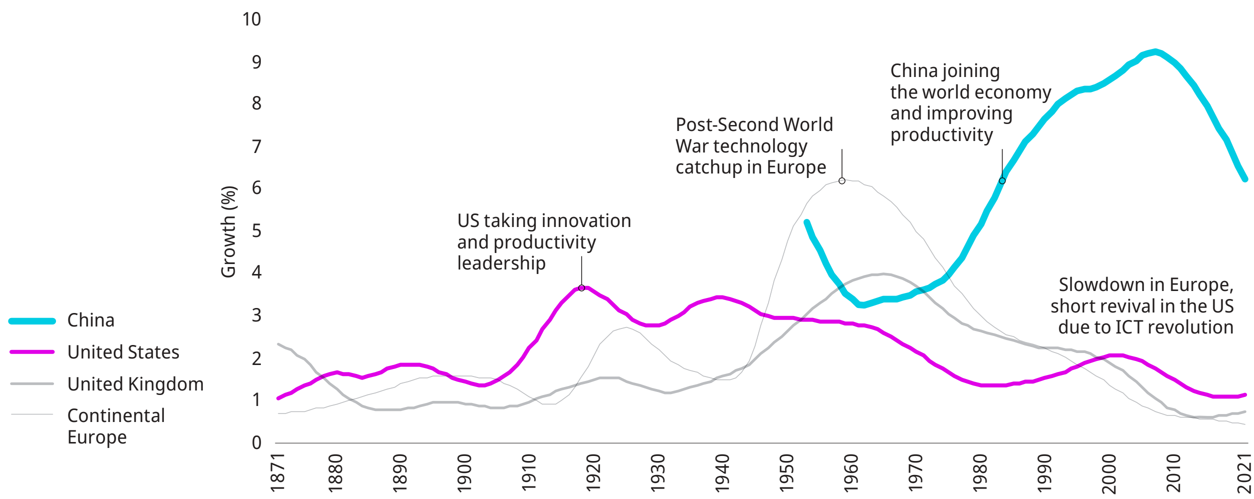
Productivity slump since the 1970s: Is the link between innovation and productivity broken?

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



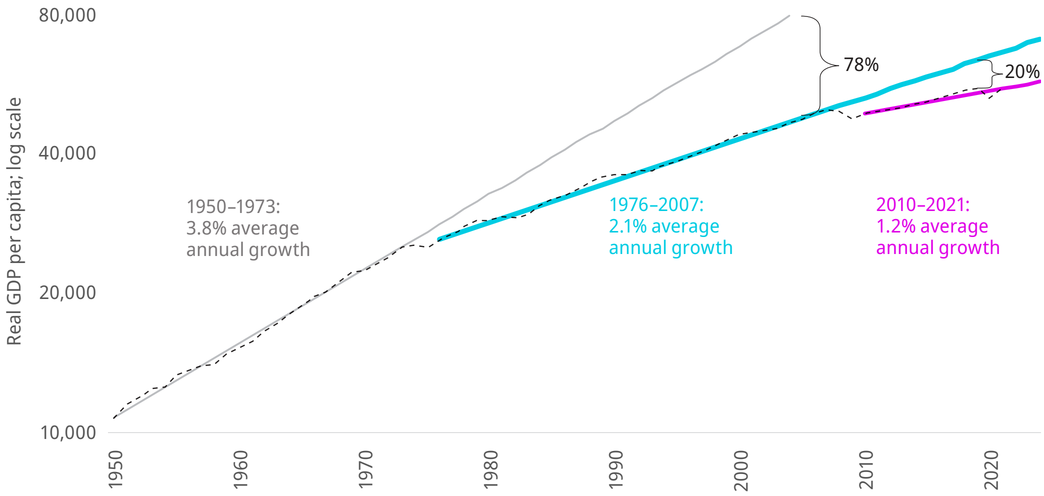
Sources: Authors' own representation based on 1870–1950 data from Bergeaud *et al*. (2016); 1950–2019 data taken from The Conference Board Total Economy Database™ (April 2022).

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.

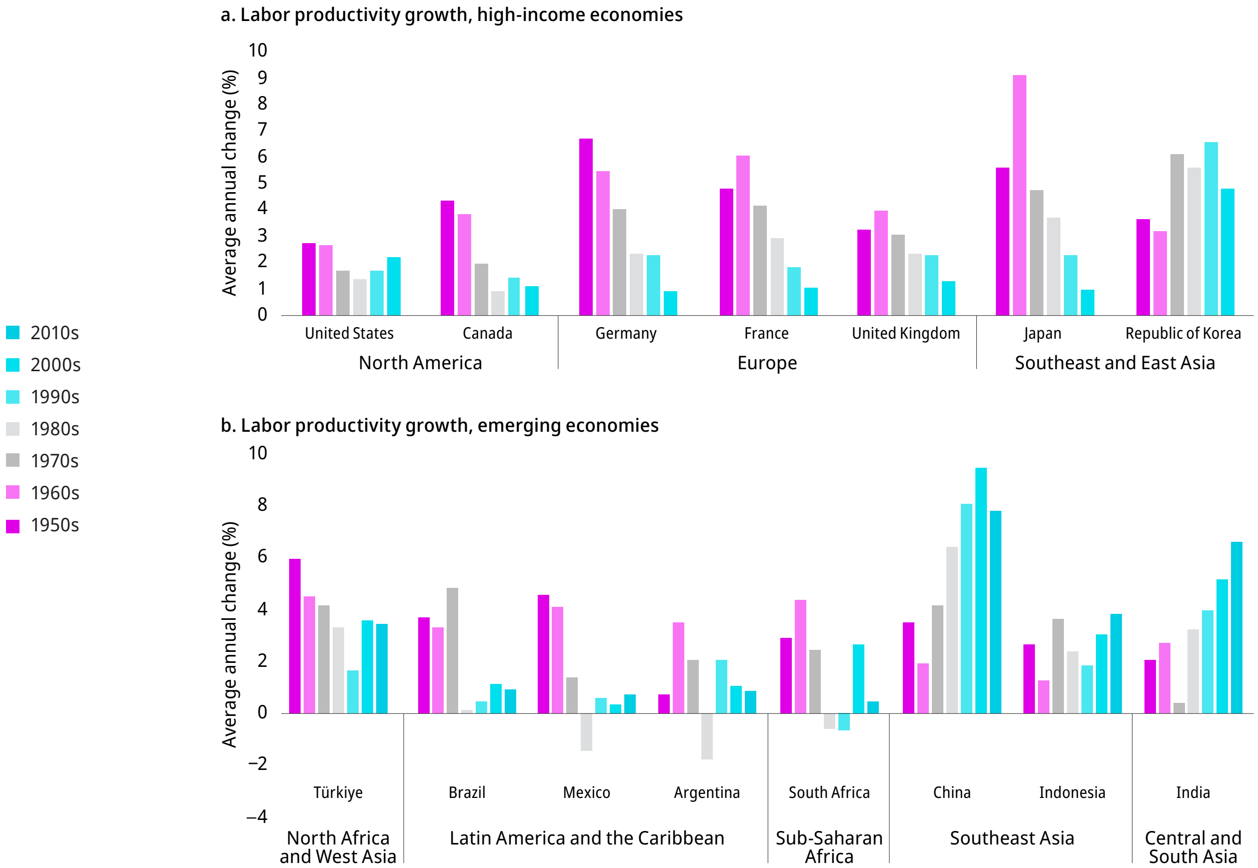
Figure 15 Slowdown in GDP per capita growth in OECD economies, 1950–2021



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]

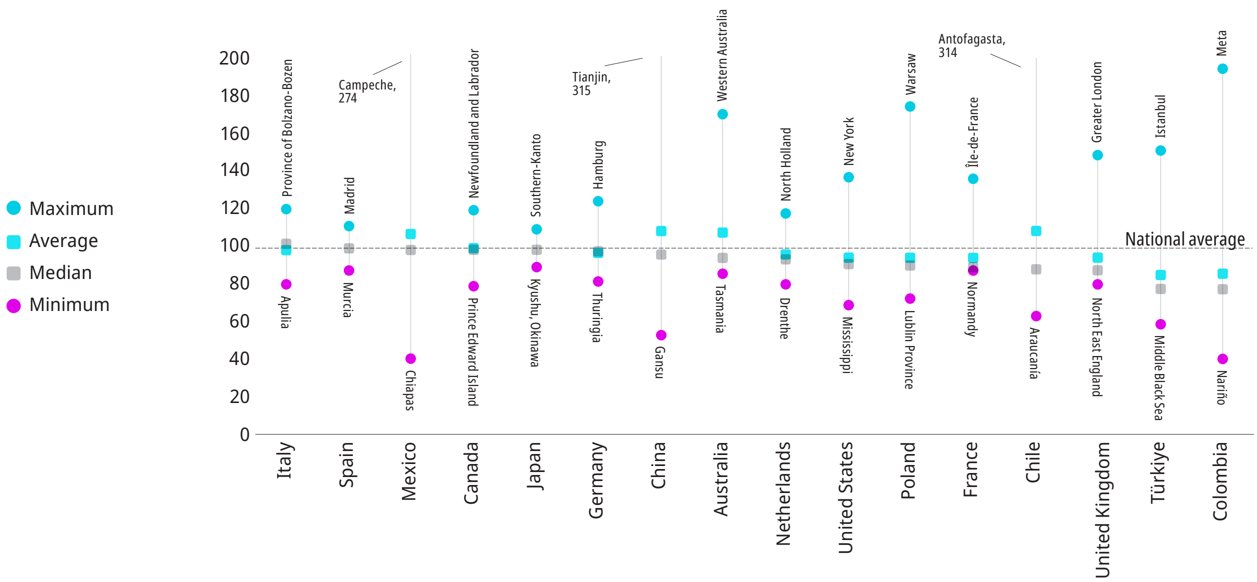
Table 10 Average productivity growth by sectors, 1996–2019 (average annual percentage change)

			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.

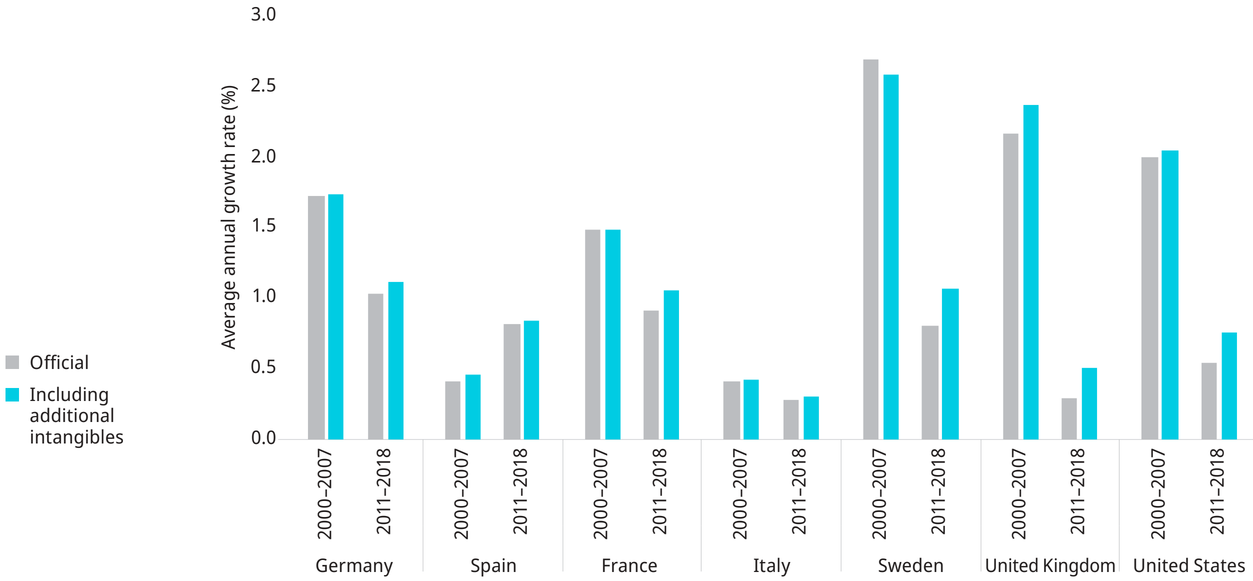
Conventions regarding the estimation of GDP (and national accounts more broadly) are updated every two decades or so to reflect a changing economy. Nevertheless, several measurement problems stand out. They are:

- 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...

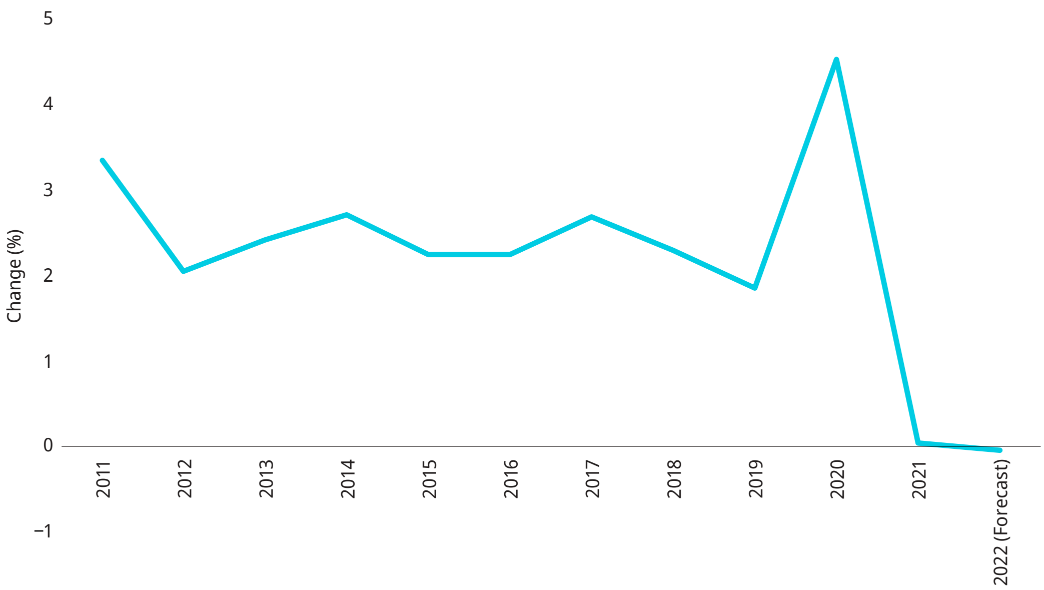
A pressing question is whether current productivity figures have experienced an uptick during, and possibly as a result of, the COVID-19 pandemic.

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

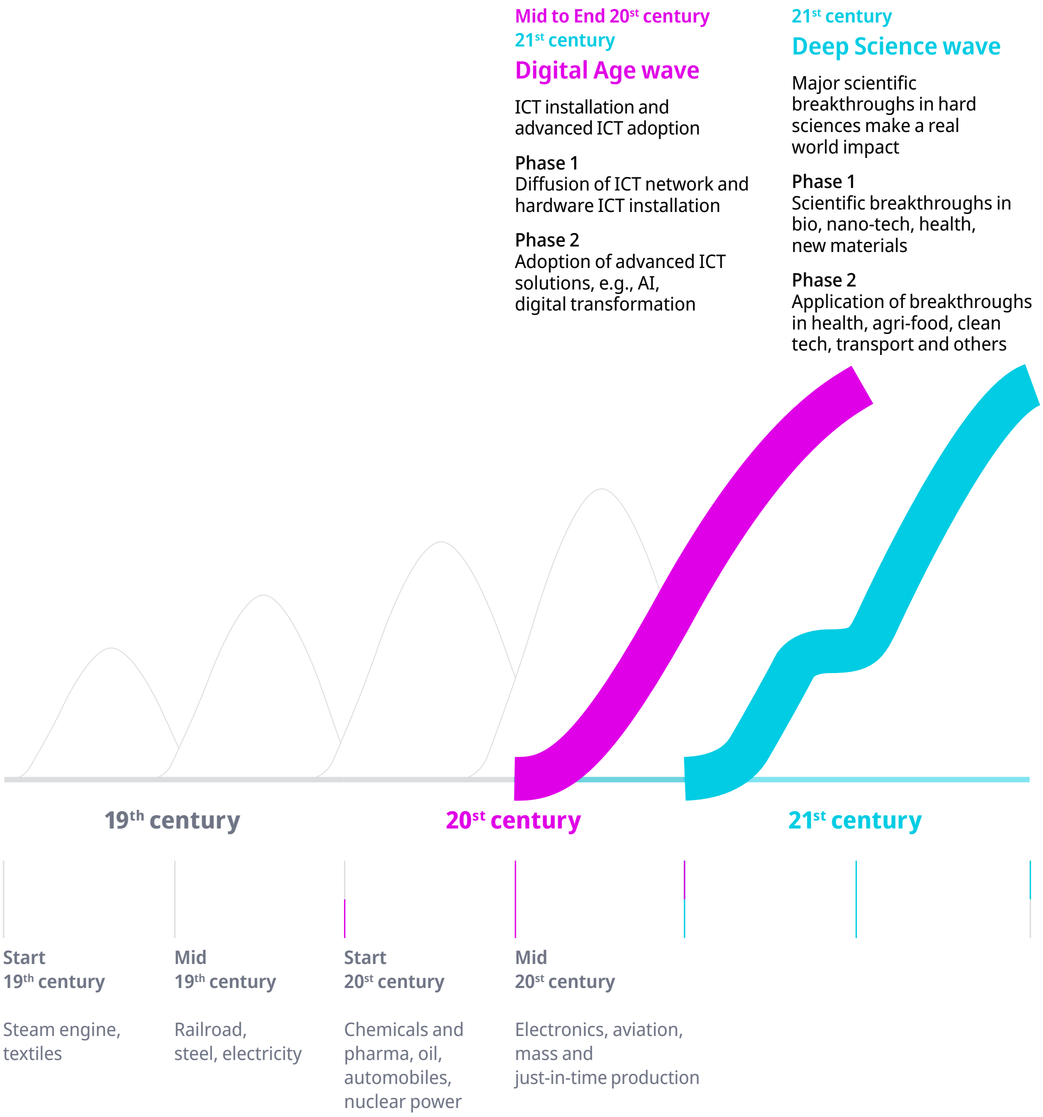
Evidence is building for two types of novel innovation waves emerging, each with the potential for large, measured – and possibly unmeasured – productivity and welfare impacts.

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.

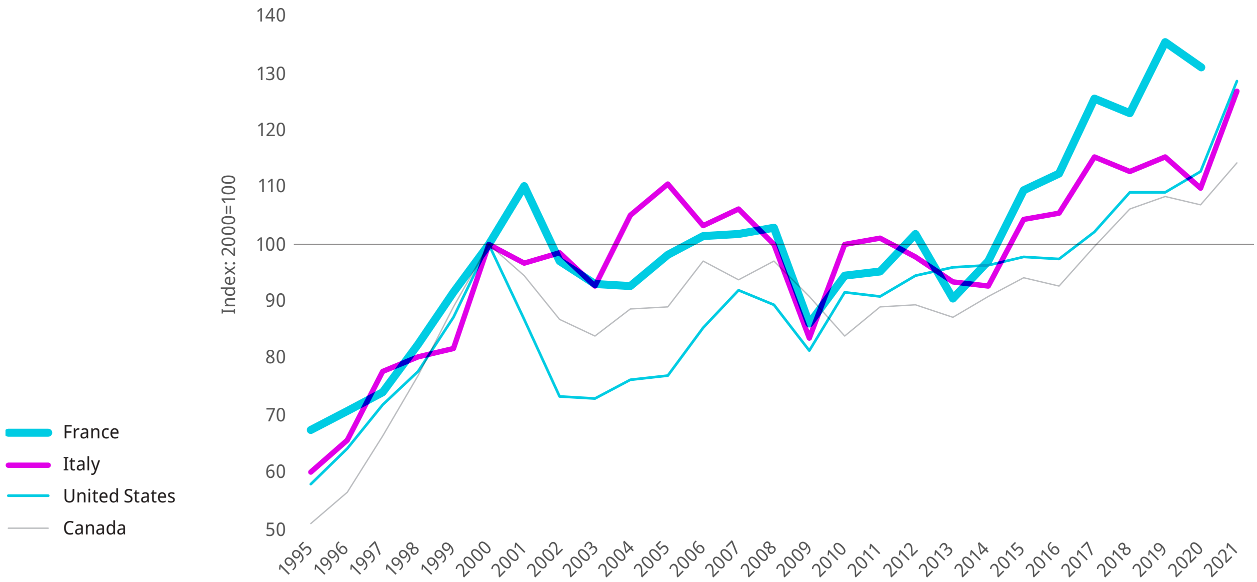
In a second surge, ICTs are diffusing as general-purpose digital technologies in the form of supercomputing, cloud computing, the internet of things (IoT), AI and automation (fueling the "New Digital Economy," as discussed in GII 2022 Expert Contribution from van Ark and Fleming).

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 health innovation systems	**New food production systems**
Novel approaches in health care research (e.g., AI)	Digital agriculture enabled by remote sensing, and geographic information systems
New ways of delivering health care (e.g., telemedicine)	Bio-controlled and artificial agro-ecosystems
	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

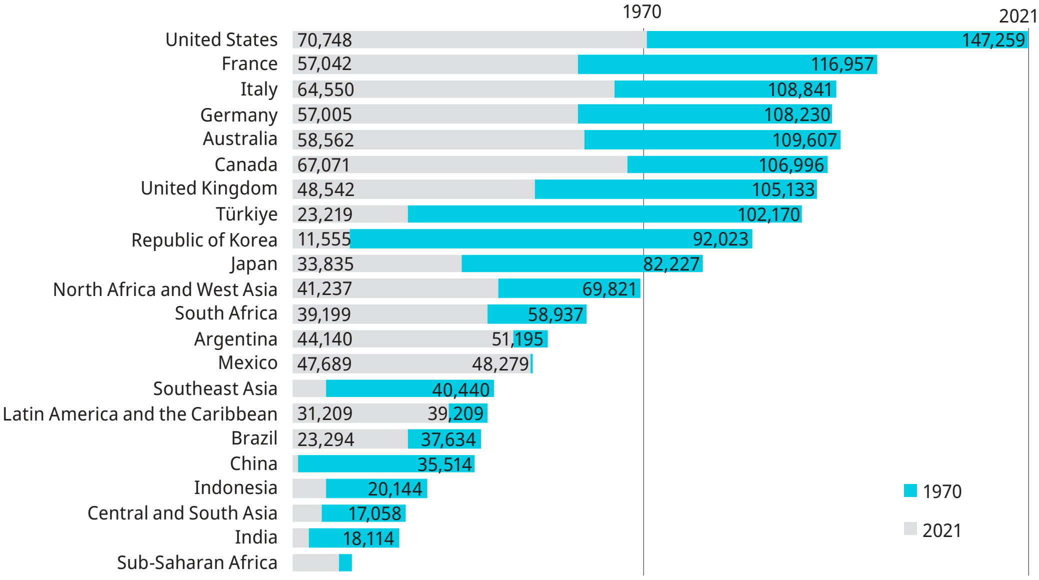
As to technological catch-up and convergence, the past three decades were an unacknowledged golden age that has led to unconditional and historic convergence.[57] This was thanks to increased globalization and what came with it in terms of knowledge diffusion and technology and innovation transfer, including 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.

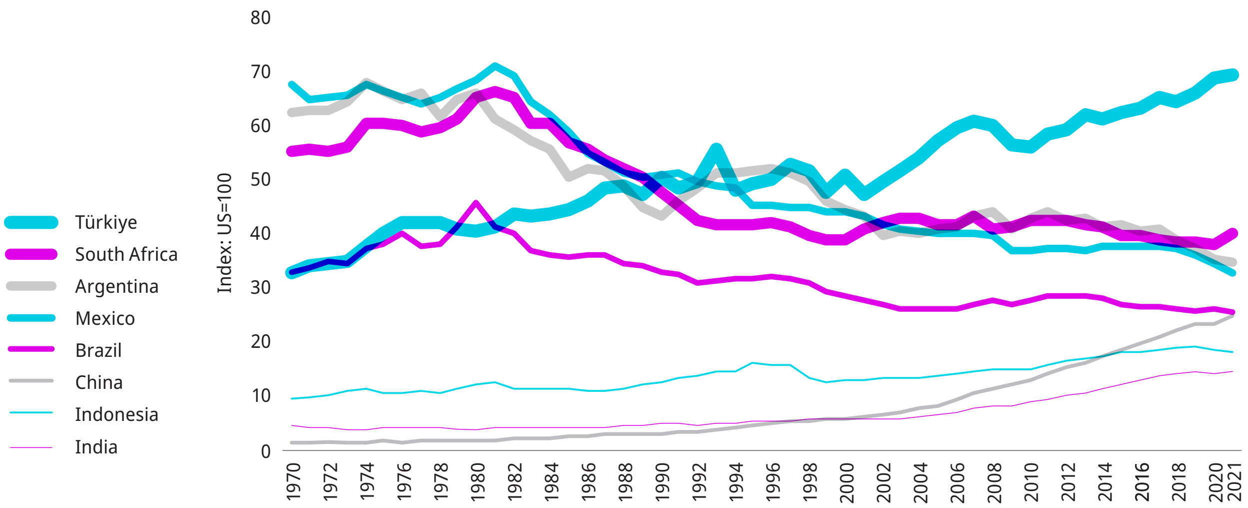
Figure 22 Productivity levels in selected major economies between 1970 and 2021



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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