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A HOLISTIC VIEW OF ICT DEVELOPMENT: INFRASTRUCTURE, R&D, AND TALENT IN DEVELOPED ECONOMIES

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INTRODUCTION

Information and Communication Technologies (ICTs) have become indispensable in the modern world, impacting nearly every aspect of society and the economy. From communication and education to healthcare and industry, ICTs have revolutionized how we interact, work, and live. One of the most significant impacts of ICTs is their role in connecting people across the globe, facilitating instant communication and collaboration regardless of geographical boundaries. Furthermore, ICTs have fuelled innovation and economic growth by enabling the development of new digital products, services, and business models. The digital economy, underpinned by ICTs, has become a significant contributor to GDP in many countries, highlighting the profound impact of these technologies on global development and prosperity.

Economically advanced countries such as the USA, EU nations, China, Japan, the United Kingdom, and India have seen the most rapid development and adoption of ICTs. Several factors contribute to this phenomenon, including strong investment in R&D, robust ICT infrastructure, supportive regulatory frameworks, and a skilled workforce. These countries also tend to have vibrant ecosystems of technology start-ups and established industry players, fostering innovation and competition in the ICT sector. Additionally, high levels of education and digital literacy among their populations further drive the demand for ICT products and services, creating fertile ground for continuous advancement and expansion in the field.

For developing countries seeking to boost their ICT sectors, an overview of ICT infrastructure, R&D, and patent activity of economically advanced nations provides valuable insights on the best practices and strategies employed by these leading countries, a clear understanding of which can help identify key areas for improvement and investment. Moreover, the analysis of how these countries have successfully developed their ICT infrastructure and fostered innovation can be a roadmap for policymakers who need evidence-based guidance that provides a solid ground for formulating strategies and initiatives to reinforce their ICT capabilities. Finally, studying patent activity and R&D efforts can guide in prioritising research areas and protecting intellectual property, essential for fostering a competitive and innovative ICT sector.

1. ICT infrastructure in developed economies: a comparative analysis

The global ICT market is dominated by the United States (35.7%), the EU (11.8%) and China (11.7%), as well as countries such as Japan (5.7%), the United Kingdom (4.5%) and India (2.4%)[1], as these countries have established themselves as technological leaders, using their strengths and capabilities (such as economic power, technological innovation, government support, infrastructure, skilled labour and global trade relations) to drive growth, innovation and competitiveness in the sector.

One of the main reasons for the dominance of these countries in the global ICT market is their economic power. In particular, the US (population of 339.9 million in 2023) and the EU (448.9 million) are among the largest economies in the world, with significant purchasing power and demand for ICT products and services, and China (1,425.7 million) and India (1,428.6 million) offer a huge consumer base for IT companies to target[2].

Developed ICT infrastructure is one of the key factors contributing to the dominance of these countries in the global ICT market, as they have strong Internet connectivity, digital networks and communication systems that support the prosperity of the ICT sector, providing a solid foundation for its further growth and expansion (Table 1). Moreover, each country has unique strengths and weaknesses in its ICT infrastructure, reflecting varying levels of development, regulatory environments, and investment priorities.

In particular, the US digital infrastructure can be characterised as follows: 3G and 4G network coverage is 100%; the average broadband speed is 154.60 thousand Kbps; total consumer spending on ICT equipment is USD 0.43 trillion; the Internet penetration rate is 94.66%; the number of households with Internet access at home in the United States is 125.10 million; the difference in broadband usage between urban and rural areas is 3.8[3] [4]. In addition, the value added of the ICT sector in the US GDP was USD 2.57 trillion. In 2022, the largest segments were digital services, digital infrastructure, software, e-commerce, and telecommunications services[5] [6].

[1] Global market share of the information and communication technology (ICT) market from 2013 to 2023, by selected country. URL: https://www.statista.com/ statistics/263801/global-market-share-held-by-selected-countries-in-the-ict-market/

[2] Worldometer. URL: https://www.worldometers.info/

[3] Going Digital Toolkit. URL: https://goingdigital.oecd.org/

[4] Digital & Connectivity Indicators – United States. URL: https://www.statista.com/outlook/co/digital-connectivity-indicators/united-states

[5] Value added to the total economy (GDP) by the digital economy in the United States from 2005 to 2022. URL: https://www.statista.com/statistics/961908/digital-economy-value-add-to-gdp/

[6] Value added to the total economy (GDP) by the digital economy in the United States from 2005 to 2022, by commodity. URL: https://www.statista.com/ statistics/961946/digital-economy-value-add-to-gdp-commodity/

We should admit, that the strengths of ICT infrastructure in the USA are advanced telecommunications network and broadband penetration (one of the fastest Internet speeds globally, with widespread availability of high-speed broadband and growing 5G networks), leadership in innovation and R&D in ICT, as well as strong ecosystem for tech startups and entrepreneurship; while general weaknesses are: digital divide in rural areas and underserved communities; privacy and cybersecurity concerns and relatively high cost of Internet services.

Table 1

Progress of developed countries in the implementation of information and communication technologies*

Indicator	USA	EU (27)	UK	China	India	Japan
High-speed fixed broadband, %	96.4	96.21	99.4	99.1	95.5	93.5
Fixed broadband cost, % GNI per capita	0.93	1.04	1.16	0.45	2.8	1.06
Mobile broadband cost, % GNI per capita	0.74	0.39	0.35	0.45	1.11	1.22
Primary schools connected to the Internet, %	-	97.56	-	98.6	20.6	-
Lower-secondary schools connected to the Internet, %	-	98.81	-	99.2	34.8	-
Upper-secondary schools connected to the Internet, %.	-	98.32	-	97.2	67.1	-
Secondary schools connected to the Internet, %	100	95.63	100	98.6	47.8	99.7
Mobile phone ownership gender parity	-	0.99	-	-	-	0.99
Individuals aged 15+ using the Internet, %	97.1	89.71	95.3	75.6	48.1	84.9
Households with Internet access at home, %	92.5	91.4	95.9	80.9	29.2	89.5
Individuals who own a mobile cellular telephone, %.	-	92.68	-	-	-	93.8
Business with 0+ staff using the Internet, %.	-	96.3	-	-	75.3	99.5
Business with 10+ staff using the Internet, %	-	98.37	96.1	-	87.2	99.5
Internet use gender parity, %	-	0.99	0.99	0.99	0.6	0.93

Source: compiled from[7]

** presented latest available data*

[7] Universal and Meaningful Connectivity. URL: https://www.itu.int/itu-d/sites/ projectumc/

China's digital infrastructure can be characterised as follows: 3G and 4G network coverage in China is 99.99%; the average broadband speed is 14.1 thousand Kbps; total consumer spending on ICT equipment is projected to reach €132.8 billion; Internet penetration is 83.7%; the number of households with Internet access is 0.44 billion[8]. Overall strengths of China's ICT infrastructure are massive investment in ICT infrastructure, including 5G networks, government support for technology development and innovation, as well as large domestic market for tech products and services; while general flaws comprise censorship and restrictions on Internet access, concerns about data security and surveillance, as well as intellectual property rights violations. Furthermore, despite significant improvements, rural areas in China still lag in terms of Internet access and quality.

The digital infrastructure of the EU-27 can be characterised as follows: 3G and 4G network coverage is 99.7%; the average broadband speed is 108.30 thousand Kbps; total consumer spending on ICT equipment is USD 128.60 billion; Internet penetration is 86.6%; the number of households with Internet access is 179 million; the difference in broadband usage between urban and rural areas is 4.4; the share of businesses with a web presence is 78%[9] [10]. Accordingly, the EU boasts extensive Internet coverage with high Internet penetration rates across member states and comprehensive regulatory framework for data protection and privacy, as well as puts strong emphasis on digital skills development and Investment in next-generation technologies. Finally, the EU makes efforts to create a Digital Single Market aiming to harmonize digital policies and enhance cross-border digital services within member states. However, the EU still has general problems related to fragmented digital market due to diverse regulations across member states, limited availability of high-speed Internet in some regions and skills gap in emerging technologies.

Japan's digital infrastructure can be characterised as follows: 3G and 4G network coverage is 99.96% and 92.88%, respectively; the average broadband speed is 141.8 thousand Kbps; total consumer spending on ICT equipment is USD 9.45 billion; the Internet penetration rate is 83.45%; the number of households with Internet access is 48.97 million; the difference in broadband usage between urban and rural areas is 1.5[11] [12]. Hence, some of Japan's strengths in developing its digital infrastructure are technologically

[8] Digital & Connectivity Indicators – China. URL: https://fr.statista.com/ outlook/co/digital-connectivity-indicators/china

[9] Going Digital Toolkit. URL: https://goingdigital.oecd.org/

[10] Digital & Connectivity Indicators – EU-27. URL: https://www.statista.com/ outlook/ co/digital-connectivity-indicators/eu-27

[11] Going Digital Toolkit. URL: https://goingdigital.oecd.org/

[12] Digital & Connectivity Indicators – Japan. URL: https://www.statista.com/ outlook/ co/digital-connectivity-indicators/japan

advanced manufacturing sector and advanced infrastructure for mobile and broadband services (a robust mobile network and widespread availability of high-speed fiber-optic networks). Nevertheless, general infrastructural disadvantages are: aging population affecting workforce in ICT sector, limited English proficiency hindering global collaborations, relatively high cost of Internet services and ICT infrastructure development and maintenance, bureaucratic hurdles decelerate the rapid deployment and adoption of new ICT technologies.

The digital infrastructure of the United Kingdom can be characterised as follows: 3G and 4G network coverage is 99.93% and 100%, respectively; the average broadband speed is 106.5 thousand Kbit/s; total consumer spending on ICT equipment – USD 36.43 billion; Internet penetration rate – 90.86%; number of households with Internet access – 27.47 million; difference in broadband usage between urban and rural areas – 4.4; share of businesses with a web presence – 83%[13] [14]. The UK has common advantages in developing and strengthening its ICT infrastructure, particularly: strong digital economy with thriving tech hubs, strong focus on cybersecurity and data protection, supportive government policies for tech startups, strong investment in ICT and digital services (ensures a significant portion of the population having access to high-speed Internet). On the other side, overall weaknesses typical for UK's ICT infrastructure are: uneven access to high-speed Internet in rural areas, relatively high costs of ICT services and infrastructure, Brexit-related uncertainties (impact on international collaboration and cooperation), some parts of the UK's ICT infrastructure require modernization, skills shortage in certain tech sectors.

India's digital infrastructure can be characterised as follows: 3G and 4G network coverage is 99.9% and 100%, respectively; the average broadband speed is 55.21 thousand Kbps; total consumer spending on ICT equipment is projected to reach USD 0.79 billion; Internet penetration rate is 98%; the number of households with Internet access is 157.40 million; the share of enterprises with a web presence is 32%[15] [16]. India's ICT infrastructure has made remarkable strides, positioning the country as a key player in the global IT market. The strengths of a robust ICT sector, a skilled workforce, cost advantages, and supportive government initiatives have driven this growth. However, to fully harness the potential of ICT, India must address the existing weaknesses, including the digital divide, infrastructure gaps, cybersecurity

[13] Going Digital Toolkit. URL: https://goingdigital.oecd.org/

[14] Digital & Connectivity Indicators – United Kingdom. URL: https://www.statista.com/ outlook/co/digital-connectivity-indicators/united-kingdom

[15] Going Digital Toolkit. URL: https://goingdigital.oecd.org/

[16] Digital & Connectivity Indicators – India. URL: https://www.statista.com/ outlook/ co/digital-connectivity-indicators/india

challenges, quality of education, regulatory hurdles, and limited R&D investment.

Additionally, most of these countries have good scores on the OECD Digital Services Trade Restrictiveness Index (DSTRI), which measures cross-industry barriers that prevent companies from providing services via electronic networks, regardless of the sector in which they operate[17]. Accordingly, the leaders in this indicator in 2022 were the United States and the United Kingdom with an index value of 0.06; Japan received a value of 0.08 points, while China (0.31) and India (0.36) are relative outsiders among the largest players in the global information and communications technology market.

In addition, it is the ICT sector that is the leader in these countries in terms of the share of intermediate consumption among all sectors of the national economy, which gives an idea of the importance of IT products and services as factors of production in the production process of other industries and an understanding of the level of integration and dependence of the national economy on the ICT sector: in the United States, this figure is 24.7%, in the EU – 35.8%, in China – 62.6%, in the United Kingdom – 27.5%, in Japan – 29.7%, in India – 23.4%[18]. Thus, the value of final demand for ICT in China is 58.4%, in the USA – 52.7%, in the EU – 49.1%, in the United Kingdom – 41%, in Japan – 55.7% and in India – 61.3%, which indicates vibrant economic activity driven by technological progress and innovation, which, in turn, support the overall economic growth of these countries[19]. Finally, it is this demand that drives investment in research and development, promotes job creation and digital transformation, ensuring the competitiveness of economies on the global stage.

2. R&D dynamics in ICT: analysing company and country-level effectiveness in developed nations

Predominantly, it is in highly developed countries that leading IT companies are based: in the USA, there are such giants as Apple, Microsoft, Amazon, Alphabet, IBM, Cisco Systems, etc.; in the EU, there to be found such reputable companies as Siemens, Ericsson, Nokia and regional divisions of American ICT companies; China is known for its corporations such as Huawei, Alibaba, Tencent, Xiaomi, Lenovo; in the United Kingdom, such

[17] OECD Digital Services Trade Restrictiveness Index. URL: https://goingdigital.oecd.org/indicator/73

[18] Intermediate consumption of information industry products as a share of total intermediate consumption. URL: https://goingdigital.oecd.org/indicator/02

[19] Final demand for information industry products as a share of total final demand. URL: https://goingdigital.oecd.org/indicator/03

companies as BT Group, Vodafone Group, TalkTalk Group, Sky Group, Virgin Media are headquartered; Japan is famous for its global leaders – Fujitsu, Sony, Hitachi, Panasonic; India – Tata Consultancy Services, Infosys, Wipro, HCL Technologies, Tech Mahindra, etc.

One of the key commonalities among these leading IT companies is their significant investment in R&D to drive innovation and create cutting-edge products and solutions. In terms of annual corporate R&D spending, (1) US companies are the global leaders, with a significant increase in R&D investment of 12.7%; (2) Chinese companies hold second position with a 16.4% increase; (3) companies from EU member states increased their R&D spending by 13.5%; and (4) Japanese companies, after years of moderate growth, significantly increased their R&D investment by over 10.4%. Finally, the share of IT companies' investments in the country's GDP in the US, for example, is 2.35%, in China – 1.84%, in the UK – 0.23%, in Japan – 2.58%[20].

It is worth noting that almost half (47 out of 100) of the top innovation leaders in 2022 belong to technology companies that sell software, computer services, hardware and other equipment. Besides, by the end of 2022, the largest volumes of FDI in R&D were in the Asia-Pacific region (USD 19.7 billion), while in Europe – USD 13.6 billion, in North America – USD 10.8 billion, in Latin America – 2.4 billion USD, in the Middle East and Africa – USD 2.1 billion[21].

In addition, IT companies from the United States are overwhelmingly the global leaders in terms of the volume and intensity of R&D investments (Table 2).

It is worth noting that in 2013-2023, in absolute terms, the global leaders in terms of R&D investments were: Amazon (387 billion USD), Alphabet (251.3 billion USD), Microsoft (191 billion USD), Samsung (185.6 billion USD), Apple (174.2 billion USD), Huawei (170 billion USD), Meta (154.4 billion USD), Intel (149.2 billion USD), Cisco (USD 70.9 billion), Oracle (USD 68 billion), QUALCOMM (USD 67.8 billion), and IBM (USD 65.1 billion).

Finally, the IT companies listed in Table 2 have a common trend of increasing R&D expenditures, in particular: Meta (43.2% annually on average), Amazon (30%), Broadcom (28%), Alphabet (20.6%) and Apple (20.3%) have the highest growth rates, while Oracle (6.1%), Samsung (4.6%), Intel (4.4%), Cisco (2.5%) and IBM (1.8%) have the lowest.

[20] Business R&D expenditure in information industries as a share of GDP. URL: https://goingdigital.oecd.org/indicator/31

[21] Top 100 global innovation leaders. URL: https://www.fdiintelligence.com/ content/ feature/global-innovation-leaders-2022-edition-82527

Table 2

Global leaders in corporate R&D spending intensity among IT companies*

Company	Main industries	R&D intensity, %		
		2021	2022	2023
Intel	semiconductors	19.2	27.8	29.6
Meta	Internet programmes	16.6	30.3	28.5
QUALCOMM	wireless equipment	21.4	18.5	24.6
Huawei	network and other types of communication, equipment	22.4	25.1	23.4
Oracle	computer software	16.1	17	17.3
Amazon	Internet commerce	11.9	14.2	14.9
Alphabet	Internet services	12.3	14	14.8
Broadcom	semiconductors	17.7	14.8	14.7
Cisco	computer networks	13.1	13.1	13.2
Microsoft	computer software	13.2	13.4	13

Source: compiled from[22] [23] [24]

** presented latest available data*

The relationship between R&D intensity and the number of patents held by leading IT companies is symbiotic: companies that invest heavily in R&D tend to generate more patents, which in turn strengthens their competitive position, stimulates innovation, and contributes to their long-term success in the global IT market. According to research, the top 100 global innovation leaders in 2023 included 37 IT companies: 15 semiconductor companies, 14 information technology providers, 8 electronics companies[25]. In addition, in terms of regions, the Americas account for 18 of the 100 innovation leaders, Asia – 10 companies, and Europe and the Middle East – 9 companies[26].

It is worth noting that the patent activity of global IT companies shows regional trends similar to the intensity of R&D expenditures: IT companies from the USA, Japan and the Republic of Korea are the most systematically active, while Chinese IT companies are gaining and maintaining the

[22] Macrotrends | The Long Term Perspective on Markets. URL:https://www.macrotrends.net/

[23] Huawei Annual Report. URL: https://www.huawei.com/en/annual-report

[24] Global 500. URL: https://fortune.com/ranking/global500/

[25] Innovation Report: The Global Top 100 Patent Organizations. URL: https://www.lexisnexisip.com/resources/stories/innovation-report/#section-Download-Report-5PPOX5eUie

[26] Innovation Report: The Global Top 100 Patent Organizations. URL: https://www.lexisnexisip.com/resources/stories/innovation-report/#section-Download-Report-5PPOX5eUie

momentum of innovation (Table 3). In addition, most IT companies choose the US jurisdiction for filing applications and receiving patent grants: by the end of 2023, Samsung had 9,036 patents registered in the US, LG had 4,170 patents, QUALCOMM had 3,886 patents, TSM had 3,719 patents, Alphabet had 2,579 patents, Apple had 2,568 patents, Huawei had 2,290 patents, Micron Technology had 2,267 patents, Intel had 2,263 patents, etc.[27].

In addition, information and communications technology is one of the areas where academic and research institutions are making significant progress in areas such as data analytics, cybersecurity and artificial intelligence, providing a comprehensive theoretical understanding and practical application of various aspects of ICT (Table 4). It is worth noting that by the end of 2023, the innovative leaders among academic institutions are the China Aerodynamics Research and Development Centre (CARDC), Zhejiang Laboratory, Electronics and Telecommunications Research Institute (ETRI Korea), Fraunhofer Society, Stanford, Massachusetts Institute of Technology (MIT), and others[28].

It should be noted that during 2006-2022, more than 4.6 million patents in ICT were granted within the jurisdiction of the countries from Table 4, in particular: more than 1.86 million patents in ICT were granted in the USA, more than 1.34 million patents – in China, more than 819 thousand patents – in Japan, more than 559 thousand patents – in the Republic of Korea, more than 34 thousand patents – in Germany, more than 26 thousand patents – in the United Kingdom and more than 24 thousand patents – in France.

It is the combination of factors such as access to ICT talents, digital and research infrastructure, a comprehensive intellectual property protection system, market demand for advanced digital technologies, government support and access to capital that creates an environment conducive to innovation and technological progress and makes these countries an attractive option for key advanced technology companies to locate their headquarters and R&D facilities (Table 5).

[27] Top 300 Organizations Granted U.S. Patents in 2023. URL: https://ipo.org/wp-content/uploads/2024/01/2024-Patent-300-IPO-Top-Patent-Owners-List.pdf

[28] Innovation Report: The Global Top 100 Patent Organizations. URL: https://www.lexisnexisip.com/resources/stories/innovation-report/#section-Download-Report-5PPOX5eUie

Table 3

Global leaders in the number of valid patents among leading IT companies*

Asia		USA		Europe	
Company	**Quantity**	**Company**	**Quantity**	**Company**	**Quantity**
Panasonic	94 337	IBM	43 033	Siemens AG	31 983
Samsung	92 724	Microsoft	31 905		
Hitachi Ltd	92 557	QUALCOMM	23 829		
Toshiba Corp	65 325	Intel	23 763	Nokia Oyj	21 213
Mitsubishi Electric	62 089	Alphabet	23 133	Tele-fonaktiebolaget LM Ericsson AB	16 809
Huawei	52 426	Apple	21 407		
Sony Group Corp	39 223	Broadcom	16 483		
Fujitsu Ltd	38 399	HP Inc	16 129	SAP SE	8 792
LG Electronics Inc	28 492	Dell Technologies	16 072		
Konica Minolta Inc	22 685	Amazon	13 522	NXP Semiconductors NV	10 248
Lenovo Group Ltd	21 215	Oracle	13 426		
TSM	17 890	Cisco	11 880		
Xiaomi Corp	14 067	Micron Technology Inc	10 061	STMicro-electronics NV	8 550
Alibaba	9 012	Applied Materials	6 701		
Ricoh	32 164	Meta	6 603		
Total	**682 605**	**Total**	**277 947**	**Total**	**97 595**

Source: compiled from [29]

** presented latest available data*

[29] IFI CLAIMS: Connect to High Quality, Global Patent Data. URL: https://www.ificlaims.com/start.htm

Table 4

Indicators of innovation potential and activity in ICT in selected countries*

Country/Indicator	USA	China	Republic of Korea	Japan	UK	Germany	France
Number of scientific papers in ICT, thousand.	75.9	182.8	18.1	18.2	25.8	27.1	16.1
Patents in ICT, thousand	136.2	230.2	41.02	44.6	2.3	2.6	1.5
Ratio of granted patents to scientific papers	1.79	1.26	2.27	2.46	0.09	0.10	0.09

Source: compiled from [30] [31]

** the latest relevant data for 2022 is provided*

Table 5

Generalised characteristics of advanced information technology markets

Advanced technology	Market value, billion USD		Growth rates (CAGR), %	Supplier companies
	2022	2032*		
AI	454.12	2575.16	19	Intel, Microsoft, IBM, Google, Amazon Web Services, Baidu, NVIDIA
Internet of Things	405.69	2703.52	23.46	Intel, Bosch Software Innovation, Amazon Web Service, Google, Microsoft, Oracle, Cisco Systems, IBM
Internet of Behaviour	402.6	3592.6	24.97	Aware Inc., Traceable, Guardian Analytics, Vertica Systems, Trifacta, Qubit Digital, Capillary Technologies
Blockchain	4.8	2334.46	85.7	IBM, Microsoft, The Linux Foundation, Circle Internet Financial, Deloitte Touche Tohmatsu, Digital Asset Holdings, Global Arena Holding

[30] Intellectual Property Statistics – WIPO. URL: https://www.wipo.int/ipstats/en/

[31] Scimago Journal & Country Rank. URL: https://www.scimagojr.com/

Big Data	199.4	686.08	14.47	IBM, Oracle, Microsoft, Amazon Web Services, Dell Technologies, Hitachi
Augmented reality (AR)	56.3	1188.98	38.33	Google, Microsoft, Samsung Electronics, Qualcomm, Niantic, Apple, AugRay
Cloud computing	480	2297.37	17	Adobe, Alibaba, Amazon, Google, Microsoft, Oracle, Salesforce

Source: compiled from [32] [33] [34] [35] [36] [37] [38]

** forecasted value*

Accordingly, when looking regionally at the main markets for advanced information technologies, the largest number and global presence of companies providing advanced technologies (e.g., AI, IoT, blockchain, Big Data, etc.) is in the United States, China, Japan, and the United Kingdom. We believe it is appropriate to summarise and provide generalised conclusions on the state of R&D and patent activity in the countries studied:

1) the USA continues to be a global powerhouse in R&D and innovation, particularly in the ICT sector, enjoying numerous strengths, including abundant funding opportunities, world-class research institutions, and a culture of entrepreneurship, but also facing challenges such as rising costs, talent shortages, cybersecurity threats, a complex patent system, increasing global competition and regulatory hurdles;

2) China's ICT sector exhibits notable strengths in R&D, including government support, a growing talent pool, strategic partnerships, and rapid technological adoption. However, challenges such as intellectual property protection, quality concerns, regulatory hurdles, and talent retention need to be addressed to sustain long-term innovation growth;

[32] Artificial Intelligence (AI) Market Size, Growth, Report By 2032. URL: https://www.precedenceresearch.com/ artificial-intelligence-market

[33] Internet of Things (IoT) Market Size 2024 to 2033. URL: https://www.precedenceresearch.com/internet-of-things-market

[34] Internet of Behaviors (IoB) Market Size, Growth, Report 2032. URL: https://www.precedenceresearch.com/internet-of-behaviors-market

[35] Blockchain Technology Market Size 2023 To 2032. URL: https://www.precedenceresearch.com/blockchain-technology-market

[36] Big Data Software Market Size, Share, Growth. URL: https://www.marketresearchfuture.com/reports/big-data-software-market-4974

[37] Augmented Reality Market Size 2024 to 2033. URL: https://www.precedenceresearch.com/augmented-reality-market

[38] Cloud Computing Market Size 2023 to 2032. URL: https://www.precedenceresearch.com/cloud-computing-market

3) The EU's ICT sector benefits from robust R&D infrastructure, collaborative initiatives, and a strong regulatory framework for intellectual property protection. Nevertheless, challenges such as fragmentation, funding constraints, skills shortages, and regulatory burdens must be addressed to maximize the region's innovation potential;

4) Japan's strengths in ICT R&D and patent generation lie in its substantial investments, advanced technological infrastructure, and strong collaboration between industry and academia. Anyhow, to sustain and enhance this leadership, Japan must address challenges such as high R&D costs, a slow patent process, demographic issues, increasing global competition, and innovation ecosystem hurdles;

5) The UK's ICT sector benefits from world-class research institutions, government support, and a thriving tech ecosystem that foster innovation and drive R&D activities. At the same time, challenges such as skills shortages, funding constraints, and regional disparities need to be addressed to maintain the UK's competitiveness and leadership in ICT innovation;

6) India's strengths in ICT R&D and patent generation are underpinned by growing investment, a skilled workforce, cost-effective operations, government support, and increasing patent filings. But despite that, to uphold and enhance its leadership, India must address challenges related to the quality of R&D output, patent system inefficiencies, limited industry-academia collaboration, infrastructure and funding constraints, and global competition.

3. Building the future: ICT talent pool in developed nations

It should be noted that the ICT sector is at the centre of digital transformation and is an important element of the economic well-being of nations, in particular, in terms of employment (Table 6). In addition, given the evolution of the global labour market in the context of the specialisation of national economies at certain stages of global production and their increasing interdependence, an interesting indicator is the share of domestic employment in the ICT sector that is used in production to meet final demand abroad (directly through the production and export of final goods and services or indirectly through intermediate products that are further processed in the country or abroad). In particular, in the United States, with 3.8% of employment in the ICT sector, approximately 0.6% of employees are involved in global value chains, in the EU (3.4%) this figure is 0.8%, in China (3.4%) – 1%, in the United Kingdom (4.6%) – 2%, in Japan (3.7%) – 0.7% and in India (0.7%) – 0.3%.

An additional competitive advantage of the countries studied is the availability of skilled and competent human capital involved in and experienced in the ICT sector, engineering, AI, IoT, Data Science and other

related fields. Besides, these countries pay considerable attention to education and training in STEM disciplines, providing themselves with a skilled workforce capable of stimulating technological progress and maintaining competitiveness in the global IT market, in particular: the share of education spending in GDP in the United States is 6%, in China – 3.3%, in the United Kingdom – 4.2%, in Japan – 3.3%, in Germany – 7.1%, in France – 6.8% and in India – 2.9% [39] [40] [41] [42]. Thus, according to the results of the Human Development Index in 2022, Germany was the leader with a score of 0.950, while the United Kingdom received 0.940 points, Japan – 0.920 points, France – 0.910 points, the United States – 0.927 points, China – 0.788 points and India – 0.644 points [43]. Furthermore, most of these countries have ensured an adequate level of access to basic education, in particular: in the United States, France, the United Kingdom, Japan and Germany, 99% of the population is literate, in China – 97% and in India – 76%[44].

In particular, in 2023, according to rough estimates, there must be 38.9 million active software developers in the world, of which: 7 million developers are concentrated in China, 5 million – in India, 4.4 million – in the USA, 1 million – in Germany, 918 thousand – in Japan, 533 thousand – in France and 465 thousand – in the United Kingdom [45] [46]. In addition, in terms of programming technologies (Table 7), JavaScript (57.8% of all developers), Java (44.9%), Python (43.4%), C++ (26.5%) and C# (26.2%).

It is worth noting that the demographic structure of the talent pool of the global IT market consists of 71.3% of men and 28.7% of women, mostly aged 25 to 34[47]. Furthermore, most developers are globally involved in product development projects for the following categories of consumer electronics: security and access products, communication devices, network

[39] U.S. Public Education Spending Statistics. URL: https://educationdata.org/public-education-spending-statistics

[40] World Bank Open Data | Data. URL: https://data.worldbank.org/

[41] UIS Statistics – UNESCO. URL: https://data.uis.unesco.org/

[42] UK education spending as a share of GDP 2023 | Statista. URL: https://www.statista.com/statistics/302002/uk-education-spending-as-a-share-of-gdp/

[43] Human Development Index (HDI). URL: https://hdr.undp.org/data-center/human-development-index#/indicies/HDI

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[45] State of the Developer Nation 25th Edition – Q3 2023. URL: https://www.developernation.net/resources/reports/state-of-the-developer-nation-25th-edition-q3-20231/

[46] How Many Software Engineers Are There in 2024? URL: https://springsapps.com/knowledge/how-many-software-engineers-are-there-in-2024

[47] How Many Software Engineers Are There in 2024? URL: https://springsapps.com/knowledge/how-many-software-engineers-are-there-in-2024

equipment, energy devices, music, video or gaming systems, household appliances, etc.[48].

Table 6

Structure of employment in the ICT sector in developed countries, %

Industry / Country	USA		EU (27)		China		UK		Japan		India	
	x_1	x_2	x_1	x_2	x_1	x_2	x_1	x_2	x_1	x_2	x_1	x_2
Computer, electronic and optical products	0.7	0.2	0.5	0.2	1.8	0.8	0.4	0.1	0.8	0.4	0.0	0.007
Publishing, audio-visual, and broadcasting activities	1	0.2	0.6	0.1	0.1	0.03	1.1	0.4	0.6	0.09	0.1	0.04
Tele-communications	0.5	0.03	0.4	0.05	0.3	0.02	0.7	0.2	0.3	0.02	0.1	0.02
IT and other information services	1.7	0.2	1.8	0.4	1.2	0.2	2.5	0.9	1.9	0.2	0.4	0.3
Total	**3.8**	**0.6**	**3.4**	**0.8**	**3.4**	**1**	**4.6**	**2**	**3.7**	**0.7**	**0.7**	**0.3**

Source: compiled from[49]

** presented latest available data*

*** x_1 – share of people employed in the ICT sector in total employment*

x_2 – share of people employed in the ICT sector that meet external demand

Table 7

Global ranking of programming languages in 2023, million people*

Language	Number of developers	The most used	Least used
JavaScript	22.5	Web, Cloud	Embedded, Device-level IoT coding
Java	17.5	Cloud, Mobile	DS/ML/AI, Embedded
Python	16.9	DS/ML/AI, app-level IoT coding	Games, Mobile
C++	10.3	App-level IoT coding, Device-level IoT coding	Cloud, Web
C#	10.2	Desktop, AV/AR	Mobile, DS/ML/AI

Source: compiled from[50]

** presented latest available data*

[48] State of the Developer Nation 25th Edition – Q3 2023. URL: https://www.developernation.net/resources/reports/state-of-the-developer-nation-25th-edition-q3-20231/

[49] Going Digital Toolkit. URL: https://goingdigital.oecd.org/

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It should be noted that with the increasing use of digital technologies and the proliferation of cybercrime, it is important to continue to prioritise cybersecurity awareness and education in order to build a cybersecurity culture [51]. According to forecasts, the negative impact of cyberattacks on the global economy will exceed USD 10.5 trillion. In addition, attackers will increasingly move to affecting information processes through social engineering attacks designed specifically to target certain industries or regions, which will weaken the protection of information based on signatures without human intervention [52] [53] [54] . Moreover, the global cybersecurity market is currently facing a staff shortage of 3.4-3.9 million specialists, which will cause more than 50% of incidents of unauthorised interference, modification or destruction of information systems in the future [55] [56] [57].

According to the study, the global cybersecurity industry has approximately 5.5 million active professionals, of which: 1.3 million are concentrated in the United States, 480.7 thousand – in Japan, 455.9 thousand – in Germany, 367.3 thousand – in the United Kingdom, 263.8 thousand – in the Republic of Korea[58]. Additionally, most cybersecurity professionals start their careers in non-cybersecurity IT positions (52%), obtaining cybersecurity certifications (51%), or learning cybersecurity concepts on their own outside

[51] Завгородня Є., Мельник Т. Розвиток програм навчання кібербезпеки в університетах: стан та перспективи. *Кращі практики розбудови європейських студій в умовах російської збройної агресії :* Зб. матеріалів Міжнар. науково-практ. конф., м. Київ, 21 жовт. 2023 р. Київ, 2023. С. 32–35. URL: https://knute.edu.ua/file/MzEyMQ==/ba77e4650ee3269072ba9f97fcfd4568.pdf

[52] Завгородня Є., Мельник Т. Розвиток програм навчання кібербезпеки в університетах: стан та перспективи. Кращі практики розбудови європейських студій в умовах російської збройної агресії : Зб. матеріалів Міжнар. науково-практ. конф., м. Київ, 21 жовт. 2023 р. Київ, 2023. С. 32–35. URL: https://knute.edu.ua/file/MzEyMQ==/ba77e4650ee3269072ba9f97fcfd4568.pdf

[53] The 10 Biggest Cyber Security Trends In 2024 Everyone Must Be Ready For Now. URL: https://www.forbes.com/sites/bernardmarr/2023/10/11/the-10-biggest-cyber-security-trends-in-2024-everyone-must-be-ready-for-now/?sh=56d586335f13

[54] Gartner Unveils Top Eight Cybersecurity Predictions for 2023-2024. URL: https://www.gartner.com/en/newsroom/press-releases/2023-03-28-gartner-unveils-top-8-cybersecurity-predictions-for-2023-2024.html

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[56] Gartner Predicts Nearly Half of Cybersecurity Leaders Will Change Jobs by 2025. URL: https://www.gartner.com/en/newsroom/press-releases/2023-02-22-gartner-predicts-nearly-half-of-cybersecurity-leaders-will-change-jobs-by-2025

[57] Cybersecurity Workforce Study 2023. URL: https://media.isc2.org//media/Project/ISC2/Main/Media/documents/research/ISC2_Cybersecurity_Workforce_Study_2023.pdf?rev=28b46de71ce24e6ab7705f6e3da8637e

[58] Cybersecurity Workforce Study 2023. URL: https://media.isc2.org/-/media/Project/ISC2/Main/Media/documents/research/ISC2_Cybersecurity_Workforce_Study_2023.pdf?rev=28b46de71ce24e6ab7705f6e3da8637e

of formal training (45%). Interestingly, obtaining a bachelor's degree in cybersecurity (31%) and higher education (master's, doctorate, etc.) in cybersecurity (20%) are less popular than all of the above paths to the profession. Below are the average salaries of cybersecurity specialists by regions (Table 8).

However, the global macroeconomic destabilisation caused by the COVID-19 pandemic and the war in Ukraine and the Middle East is forcing organisations to make decisions to optimise corporate costs (including budget cuts, layoffs, hiring and promotion freezes), which in the context of cybersecurity teams is increasing the vulnerability of confidential information to cyberattacks. Currently, the global cyber threats landscape is the most complex in the last 5 years, and this indicator varies by industry: the highest sensitivity to external threats is reported in healthcare, the military-industrial complex and law enforcement agencies, energy and utilities, public administration, and industry; the lowest sensitivity (but still high) is reported in the automotive, construction, and telecommunications sectors.

Ultimately, according to cybersecurity experts, the following new technologies/cybersecurity architectures will have the greatest positive impact on the ability to protect organisations' information space from cyber threats: automation in cybersecurity, zero-trust policy in access to the corporate network, advances in AI, risk-based cyber vulnerability management, passwordless authentication, advanced cyber threat detection and response system, Zero Trust Edge architecture, quantum computing, hardware/software security, increased computing power and speed, blockchain, growth of edge computing, reduction of the impact of the AP form factor, telecommunications improvements (e.g., introduction of 6G technology) and development of mobile computing[59].

Table 8

Average annual salaries of cybersecurity professionals by category in 2023, thousand USD*

Category / Region	World	Asia	Europe	North America
Certified Information Systems Security Professional	119.6	70.8	103.5	147.8
Systems Security Certified Practitioner	94.9	73.9	102.3	108.2
Certified Cloud Security Professional	114.2	83	111.7	148

[59] Cybersecurity Workforce Study 2023. URL: https://media.isc2.org/-/media/Project/ISC2/Main/Media/documents/research/ISC2_Cybersecurity_WorkforceStudy2023.pdf?rev=28b46de71ce24e6ab7705f6e3da8637e

Certified Specialist in Governance, Risk and Compliance	110	85	122.5	134.5
Certified Secure Software Lifecycle Professional	115.8	84.7	138.2	147.4
Information Systems Security Architecture Professional	118.9	81.9	129.7	146.2
Information Systems Security Engineering Professional	109	74.5	147.6	159
Information Systems Security Management Professional	106.9	81.9	144.2	146.4

Source: compiled from[60]

** presented latest available data*

Finally, each studied country has unique strengths and weaknesses in ICT talent development, reflecting their efforts to nurture a skilled workforce for the digital economy, in particular:

1) USA has strengths in producing skilled ICT professionals, fostering a tech start-up ecosystem, attracting global talent through major tech companies and career growth opportunities. Nevertheless, weaknesses include shortages in specialised areas like cybersecurity and data science, as well as disparities in access to ICT education;

2) the EU focuses on STEM education and training, encouraging a skilled ICT workforce and promoting cross-border talent mobility and diversity, as well as gender and minority representation. At the same time, it faces challenges, such as variation in ICT education quality, limited specialised skills in emerging technologies;

3) Among China's ICT sector strengths are: a large pool of graduates, government initiatives, and growing global talent attractiveness due to career opportunities and R&D investment. Anyhow, weaknesses include disparities in education quality, need for critical thinking and creativity, and language barriers affecting international talent recruitment and collaboration;

4) UK has strengths in ICT education and training, attracting talent globally, and supportive government policies for talent development. Anyway, Brexit uncertainties impact ICT talent mobility, specialised skills shortages in cybersecurity and data analytics;

5) Japan's ICT sector strengths include lifelong learning, strong industry-academia collaboration, and traditional values of discipline and dedication. But for all that, weaknesses include language barriers, limited diversity in the tech workforce, and a need for greater emphasis on creativity and innovation in ICT education and training;

[60] ISC2: Cybersecurity Certifications and Continuing Education. URL: https://www.isc2.org/

6) India has a large pool of ICT graduates with strong technical skills, a thriving startup ecosystem, and a growing emphasis on diversity and inclusion in the tech workforce. But still, it faces challenges like disparities in access to quality education, a need for soft skills development, and brain drain.

CONCLUSION

The global IT market is dominated by the US, EU and China, with other key players such as Japan, the UK and India. These countries have established themselves as technology leaders by leveraging their inherent strengths and capabilities. Factors contributing to their dominance include significant economic power, a large consumer base, advanced technological innovation, adequate government support, well-developed infrastructure, a highly skilled workforce, and extensive global trade links. These elements combine to foster growth, innovation and competitiveness in the ICT sector.

The US ICT sector is at the forefront of technological progress and digital transformation, playing a crucial role in shaping various industries, increasing productivity and stimulating innovation on a global scale. In order to maintain a strong competitive position in the global information and communications technology market, US IT companies continue to invest in R&D and massive deployment of advanced technologies and place a high priority on cybersecurity.

The EU ICT sector is dynamic and fast-growing, fuelled by technological advances, digital transformation initiatives and growing demand for communications and connectivity solutions. In addition, the EU ICT sector is represented by a wide range of technologies and services, including telecommunications, software development, ICT services, Internet services and hardware manufacturing. However, to maintain its global competitive advantage, the EU needs to effectively address issues such as data privacy, ICT infrastructure constraints and cybersecurity threats.

China's ICT sector is experiencing significant growth and boom, driven by rapid urbanisation, internet penetration and numerous government initiatives to promote digitalisation in all areas of the society. At the same time, the main constraints to China's global dominance as a digital power include issues related to cybersecurity and data privacy (in particular, content censorship, localisation and data transfer, as well as entry of foreign companies into the market); lack of ICT talents (in areas such as data science, AI, cybersecurity, etc.), which is necessary to meet the requirements of the rapid pace of digitalisation in the country.

The UK ICT sector is experiencing growth due to the increasing adoption of ICT across various industries, as organisations recognise the critical impact of digital technologies in ensuring the global competitiveness of the national

economy, improving operational efficiency and delivering a seamless customer experience.

The ICT sector in Japan is most advanced in the areas of telecommunications, software development and hardware, which are making headway due to technological progress and digitalisation of various sectors of the national economy. The main factors that may adversely affect Japan's competitive position in the global IT market include: the problem of the nation's ageing, which affects the availability of the talent pool and consumer base and a complex system of government regulation of digitalisation and the ICT sector, which becomes a barrier to market entry.

Finally, India's ICT sector has also experienced rapid growth and transformation in recent years, notably due to numerous digitization initiatives, improved quality and availability of the Internet, favourable government policies, low labour costs, as well as increased demand for IT, software, and communications services.

SUMMARY

The first section of the study examines the state-of-the-art ICT infrastructure in leading economies, analysing the deployment of high-speed Internet, advanced telecommunications networks, and supportive regulatory frameworks that facilitate robust digital ecosystems. The second section of the study covers the R&D dynamics within the ICT sector, evaluating both company and country-level effectiveness in fostering innovation. This section highlights significant investments in research, the development of cutting-edge technologies, and the role of intellectual property protections in promoting a thriving ICT industry. The final section of the study investigates the composition and capabilities of the ICT talent pool in developed nations. We believe that the synthesis of insights from these three dimensions may provide valuable lessons and form the basis of further strategic recommendations on enhancing ICT ecosystems, fostering innovation, and promoting inclusive growth in the digital economy.

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