Artificial Intelligence

Understanding the Current Technology Landscape through Patent Analytics

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Executive Summary

Artificial intelligence (AI) has experienced an unprecedented evolution, establishing itself as a cornerstone of global technological advancement. Its versatility as a general-purpose technology has transformed various industries by improving efficiencies, automation, personalised services, and security.

As countries race to develop their own AI ecosystems, understanding the current technology landscape becomes crucial for making smart decisions that drive innovation in the AI technology space.

1. AI technology is a global innovation focus.

Emerging from periods of reduced funding and waning interest, AI has made an impressive comeback, demonstrating its influence across diverse industries since the start of the 21st century.

Over the last decade, more than 680,000 AI-related inventions have been published globally, with a high compound annual growth rate (CAGR) of 33.1% from 2017 to 2022 – roughly 10 times faster than the global patent growth rate.

Asia stands out as the epicentre of the world's AI innovations, accounting for more than 80% of the global output. North America and Europe are ranked second and third, with 79,000 and 26,000 inventions, respectively. This global picture highlights a strong focus on AI innovation in different countries, characterised by a significant rise in AI-related inventions at a national level.

2. Countries are leveraging their unique strengths to leap ahead in the global AI race.

China and the U.S. are frontrunners in AI innovation, jointly contributing nearly 80% of global AI innovation. This leadership is supported by several key factors: both countries boast large talent pools and are home to major data centres and digital platforms that provide abundant data for advancing AI.

China's progress in AI is driven mainly by government initiatives, unlike in the U.S., where the private sector takes the lead in driving AI innovation.

Elsewhere in the world, South Korea is strategically broadening its ICT expertise into AI, while Canada builds on its history of pioneering AI research. In Israel, it is the country's start-ups that are a major driving force in AI innovation.

Meanwhile, the U.K. has established a nurturing environment for AI businesses to support growth and innovation, while other European nations use AI to secure industrial sovereignty and bolster their global technological positions.

3. Well-explored machine learning and deep learning form the bedrock for diverse practical applications.

With around 320,000 inventions published globally in the last decade, machine learning and deep learning have been thoroughly explored. They continue to be dynamic hubs of innovation, with ongoing technological breakthroughs that tackle complex real-world challenges.

Building on the strong foundation in machine learning and deep learning, practical uses of AI in computer vision and natural language processing have experienced significant growth, with about 131,000 and 110,000 inventions worldwide, respectively. The well-developed field of computer vision and natural language processing is vital for advancing industrial applications.

4. Edge computing hardware is strongly emerging.

AI hardware is quickly becoming a crucial part of AI use in various industries, with around 4,000 inventions registered worldwide in the past decade and an impressive CAGR of 57.9% from 2017 to 2022.

In the field of AI hardware, one area that has garnered significant attention is edge computing hardware, which has grown by 187 times, compared to the broader AI hardware landscape's 14-fold rise in the past decade.

Although the sector is still new with about 400 inventions, established players in the AI hardware domain are exploring this specialised space. The presence of start-ups among these leading innovators underscores the potential of AI hardware for edge applications.

5. Explainable AI is an emerging field crucial to meeting the specific requirements of various applications.

Explainable AI is an essential component for building trust for AI adoption. Despite its significance, there were only around 3,500 related inventions published between 2013 and 2022, which is a small portion compared to the broader AI technology field.

While there has not been much innovation in explainable AI, its importance is highlighted by the specific needs of different applications. Certain applications, such as image recognition, prioritise high accuracy, whereas others like medical

diagnosis demand both accuracy and interpretability. Striking a balance between explainability and performance is crucial to meeting diverse application needs and ensuring that AI is used responsibly.

6. Industrial applications of AI are just emerging.

Built on a strong foundation of extensive technological advancements, AI is beginning to impact various industries, including healthcare, transport, finance and cybersecurity. Unlike AI technologies, however, industrial applications of AI are still emerging with a smaller body of accumulated technology, most of which has been published in recent years.

The healthcare industry, recognised as the most valued sector with high innovation interest globally, relies heavily on machine learning and deep learning techniques. These techniques are applied in many scenarios, such as disease diagnosis, workflow optimisation, and drug design simulation.

Natural language processing is used for analysing health records and developing automated conversational agents, while computer vision is integral to medical image analysis. The finance, cybersecurity, and transport sectors are of particular interest to some countries, which have specific use cases in these sectors, including fraud detection, threat analysis, and autonomous driving.

7. AI for healthcare presents opportunities for further development.

Over the past decade, AI applications in healthcare have registered more than 65,000 inventions globally, establishing the sector as an innovation hotspot. Current developments mainly target treatment, therapies, and health administration, while applications in sports, fitness, and healthcare research are in the early stages.

Despite significant technological progress, the full potential of AI in healthcare is yet to be realised. The landscape lacks dominant players; instead there is a mix of multinational corporations, new entrants, start-ups, and research entities across all areas. This environment is also marked by increased merger and acquisition activities, which offer opportunities for further development.

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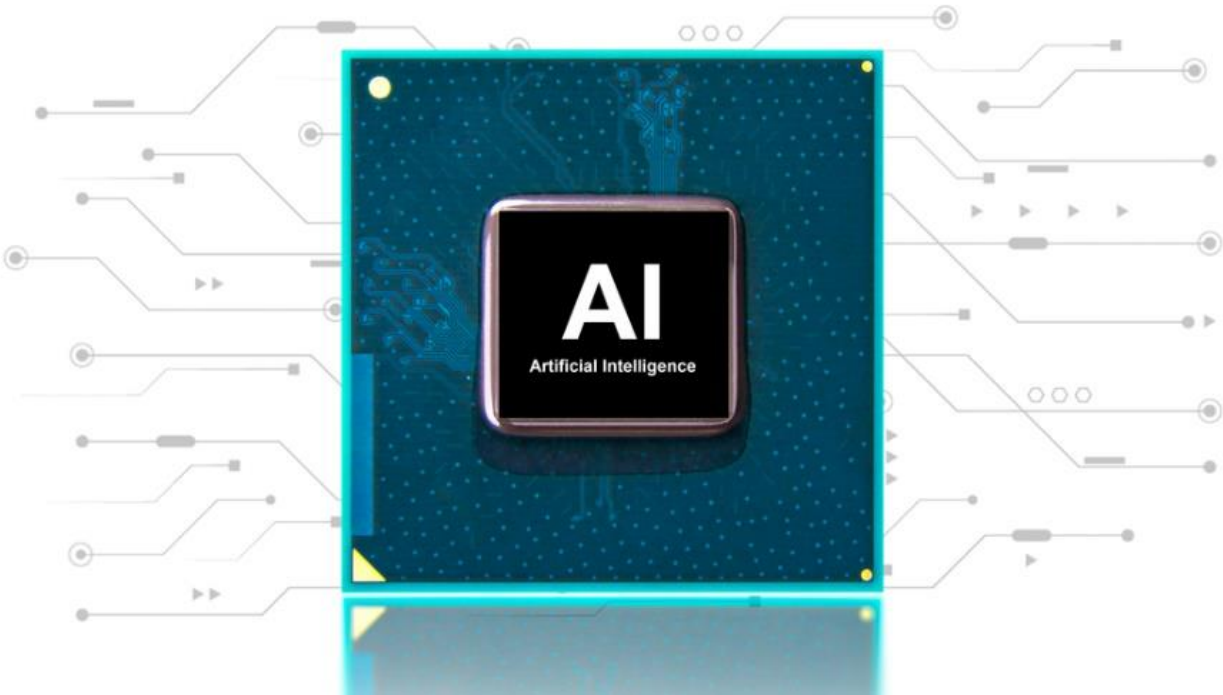
Introduction

The current rise of AI is rooted in a rich history of technological progress. From the early days of symbolic AI to the recent breakthroughs in deep learning, the field has witnessed exponential growth. The 21st century has seen AI evolve into an incredibly powerful force, thanks to the widespread use of sensors and abundant data. This era of AI is defined by landmark achievements, such as the development of the neural network-based AlphaGo, which demonstrated AI's ability to outperform humans in complex tasks.

AI, which is known as a general-purpose technology, has become essential across diverse industries. Beyond general applications, AI has revolutionised healthcare through predictive analytics and personalised treatment plans; it has transformed financial services with fraud detection algorithms; and it has enhanced manufacturing with predictive maintenance and automation.

These examples show how AI can boost efficiency, improve personalisation, and enhance security across sectors. However, the journey of AI integration is far from complete, as many industries are still exploring how AI can benefit them, suggesting there is untapped potential to be discovered.

These efforts are part of a larger global initiative to harness AI's transformative potential. Countries worldwide are using their strengths to pull ahead in the AI innovation race, which is marked by strategic investments, policy frameworks, and collaborative research efforts aimed at fostering innovation while addressing the ethical, social, and economic implications of using AI. Understanding this landscape is crucial for making informed decisions that drive innovation in AI amid global competition and cooperation.



Scope and Objectives of the Study

This report examines the AI landscape based on related patent applications published worldwide in the last decade (2013-2022). Specifically, three major pillars were studied: country highlights, AI technologies, and industrial applications (**Exhibit 1**).

In addition to patent data, the study considered other factors, such as country policies and market and business intelligence. The analysis aims to provide a multi-faceted and holistic assessment of the current AI landscape, with the objectives of assessing the maturity of the technologies and identifying promising research opportunities to aid R&D planning and policies.

Exhibit 1: Scope of the study[1]

Artificial Intelligence (AI)

Country Highlights			
• U.S. • China • U.K.	• Canada • Israel • South Korea	• Germany • Netherlands • Finland	• Sweden • Denmark • Singapore
AI Technologies			
Machine Learning & Deep Learning • Reinforcement Learning • Federated Learning • Transfer Learning • N-shot Learning • Long Short-Term Memory (LSTM) • Transformer	Functional Applications • Natural Language Processing • Computer Vision	Explainable AI	AI Hardware
Industrial Applications			
• Education • Healthcare • Finance	• Cybersecurity • Transport • Logistics	• Manufacturing • Border Security	• Smart Estates • Government

[1] The scope was co-developed with input from the National AI Office, Singapore.

Global Innovation Trends

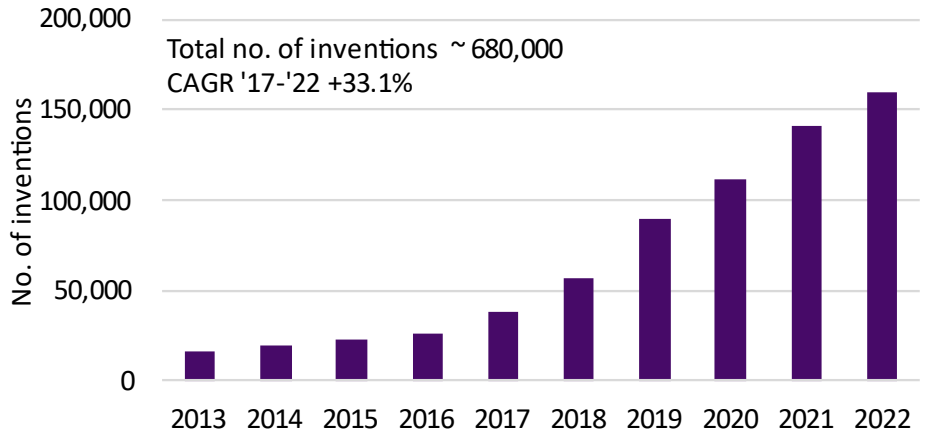
Since its beginnings in the 1950s, AI has faced challenges, including two winters characterised by reduced funding and waning interest. However, things started to change towards the turn of the 21st century, signalling a comeback for AI. Across diverse industries, from service robots like the Roomba to gaming innovations like the Xbox 360 Kinect, AI has demonstrated notable successes. Milestones such as IBM's Watson triumphing in Jeopardy and Google's autonomous cars driving one million miles proved its transformative impact.

Over the past decade, there have been over 680,000 AI-related inventions. The last five years, in particular, saw a surge in innovation, marked by a high CAGR of about 33.1% (**Exhibit 2**).

Several factors have contributed to this new AI era, including the widespread use of sensors that collect data. This abundance of data, coupled with increased computing capabilities at a lower cost, has driven AI progress. Advancements in AI algorithms, particularly through deep learning models, have broadened the scope of AI applications. Open-source initiatives, exemplified by TensorFlow and PyTorch, have reduced barriers to AI adoption. The influx of private and public AI funding also signals a robust growth trajectory.[2][3]

Exhibit 2: Global innovation trend of AI

The high CAGR of 33.1% from 2017 to 2022 is approximately 10 times the growth of global overall patenting.



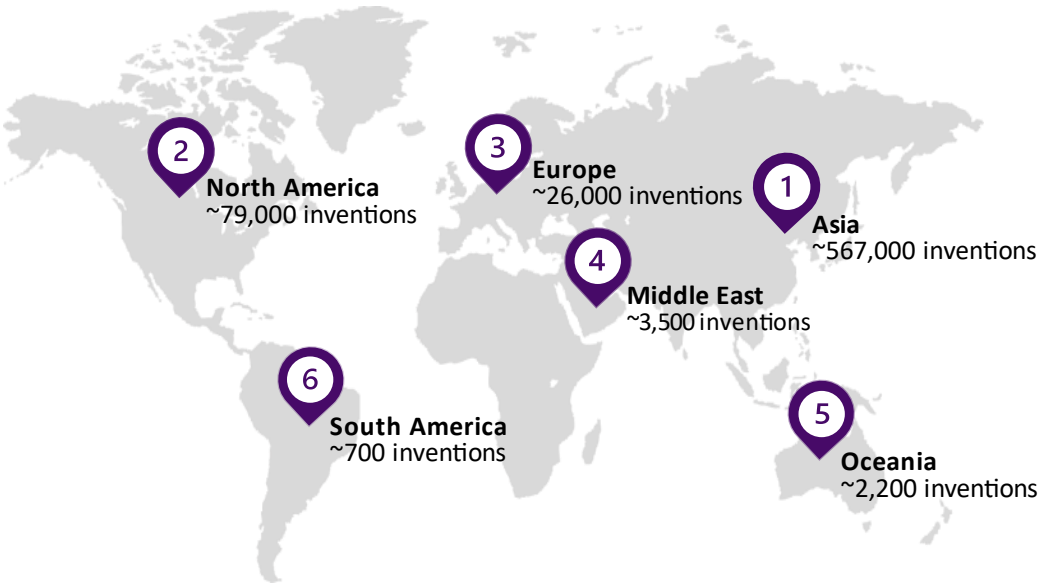
No. of inventions is based on unique patent families published worldwide in 2013-2022.

[2] Statistica, *Artificial intelligence (AI) startup funding worldwide from 2011 to 2023 (in billion U.S. dollars), by quarter*

[3] OECD.AI, *A new approach to measuring government investment in AI-related R&D*, 5 Jul 2021

Exhibit 3: Distribution of AI innovations by place of origin

AI innovations are concentrated in Asia, North America, and Europe.



Asia	North America	Europe	Middle East
China [457,512]	U.S. [76,304]	Germany [9,001]	Israel [1,957]
South Korea [44,249]	Canada [2,653]	U.K. [3,393]	
Japan [43,458]		France [2,584]	
		Netherlands [2,104]	
		Sweden [1,334]	
		Finland [982]	
		Denmark [342]	

Number in the brackets denotes the volume of inventions published in 2013-2022.

AI innovations are concentrated in three regions (**Exhibit 3**). Asia is the hub of the world's AI innovations, contributing over 80% of global output. North America and Europe are ranked second and third, with 79,000 and 26,000 inventions, respectively.

In Asia, alongside pivotal innovators China and South Korea, Singapore has emerged as a notable player, producing about 1,400 inventions despite its small size. Notably, the U.S. and Canada are leading innovation efforts in North America. In Europe, innovation is more widespread geographically, with contributions from multiple countries. Apart from these regions, Israel also stands out as a significant contributor to global AI innovation efforts.

Exhibit 4: Country key AI innovation statistics

	China [457,512]	U.S. [76,304]	S.Korea [44,249]	Germany [9,001]	U.K. [3,393]	Canada [2,653]	Netherlands [2,104]	Israel [1,957]	Singapore [1,396]	Sweden [1,334]	Finland [982]	Denmark [342]
Share of global AI innovation [a]	67.3%	11.2%	6.5%	1.3%	0.5%	0.4%	0.3%	0.3%	0.2%	0.2%	0.1%	0.1%
Country-level AI innovation focus [b]	5.5%	5.2%	4.6%	1.8%	3.9%	4.1%	3.7%	6.6%	4.9%	2.8%	3.7%	1.9%
Innovator concentration [c]	11%	29%	30%	61%	31%	27%	85%	24%	65%	73%	81%	49%

[a] Country's AI inventions/Global total AI inventions (%)
[b] Country's AI inventions/Country's total inventions (%)
[c] Total no. of inventions of country's top 10 AI innovators/Country's AI inventions (%)

China and the U.S. lead the way in AI, jointly contributing nearly 80% of global AI innovation (**Exhibit 4**). This leadership is supported by several key factors. Firstly, both countries host hyperscale data centres and digital platforms that provide ample data to advance AI technology. Secondly, a large pool of talent is available to spur innovation growth. Together, the two countries produce 50% of the world's leading AI talents and attract 70% of the globe's top AI researchers.[4] This combination of data infrastructure and talent underscores their roles in driving AI innovation on a global scale.

China and the U.S. stand as pre-eminent leaders in AI innovation.

Across various nations, there is a strong emphasis on AI innovation, evident through country-level data (**Exhibit 4**). China, for example, has generated 457,512 AI-related inventions, comprising 5.5% of the country's total inventions from 2013 to 2022. This contrasts with the earlier decade (2003-2012), where China's AI-related inventions represented only 1.2% of the nation's total inventions. Similar trends can be observed in other countries, highlighting the shared global commitment to advancing AI technologies.

[4] MacroPolo, The Global AI Talent Tracker

When it comes to innovation, larger countries such as China and the U.S. have a lower concentration of innovators because AI is pursued across many organisations.[5] In contrast, smaller nations like Singapore have a higher concentration driven by a select group of key contributors (**Exhibit 4**). China, in particular, stands out with a highly diversified innovator profile. The Chinese ecosystem comprises several players in the AI space, including not only prominent companies and research institutions but also smaller entities integrating AI into their specific business domains. This widespread adoption is evident both within organisations and among consumers, who actively seek AI-enhanced products and services. This indicates a growing societal comfort and eagerness to embrace AI advancements.

[5] See Annex C: Exhibit C-1 for the list of top 10 AI innovators in each country

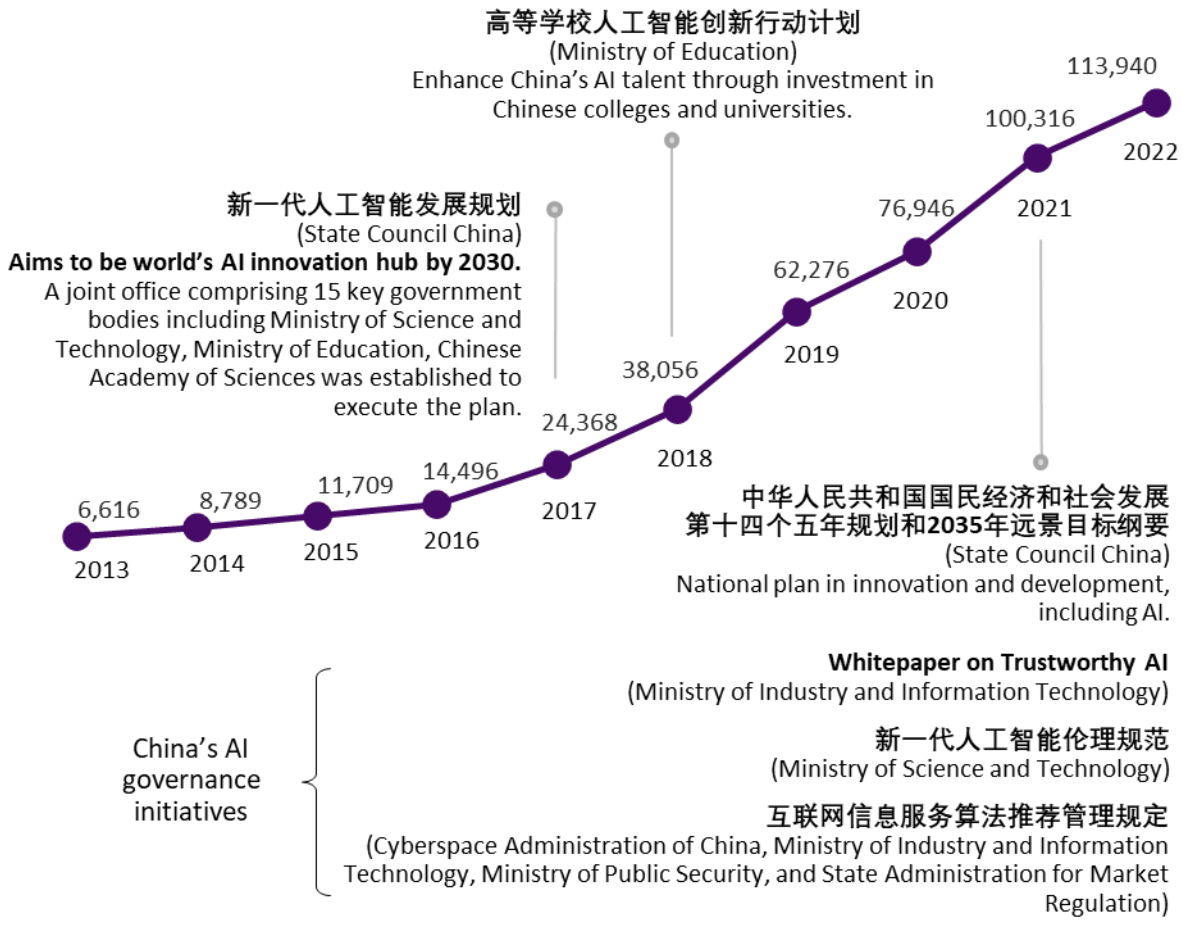
Country Highlights

As AI becomes more widespread, nations are using their distinctive strengths to develop tailored AI ecosystems to secure a competitive advantage. This requires close collaboration among governments, businesses, and public research entities to create environments that support innovation, from research initiatives to successful commercialisation.

China

China has strategically prioritised science and technology in its national agenda to drive development and boost economic competitiveness. AI, in particular, is seen as a transformative force to bring profound economic and societal changes.

Exhibit 5: China's AI patenting trend and key AI policies and plans



China's meteoric rise in AI patenting is closely tied to its national plans and vision (**Exhibit 5**). With a solid foundation laid in earlier years, AI innovation began in 2017 with the release of the "New Generation Artificial Intelligence Development Plan". [6] This national plan outlines key priorities for AI development and sets an ambitious goal for China to become a global AI innovation hub by 2030. The commitment to using AI for economic growth has been reiterated in subsequent policy papers, firmly positioning China as a leader in the AI space.

In its pursuit of global AI innovation leadership, the Chinese Ministry of Science and Technology formed a national AI team to steer industry-led open innovation platforms. Since 2017, 15 prominent technology companies, including Baidu, Alibaba, and Tencent, have played key roles in spearheading AI development. For instance, Alibaba's smart city product, the ET City Brain, was successfully tested in Hangzhou and later expanded to major Chinese cities, as well as international hubs like Kuala Lumpur and Dubai. This highlights the global impact of China's focused AI initiatives.

China's strides in AI development are primarily fueled by government initiatives, in contrast to the U.S. where the private sector plays a leading role in driving AI innovation.

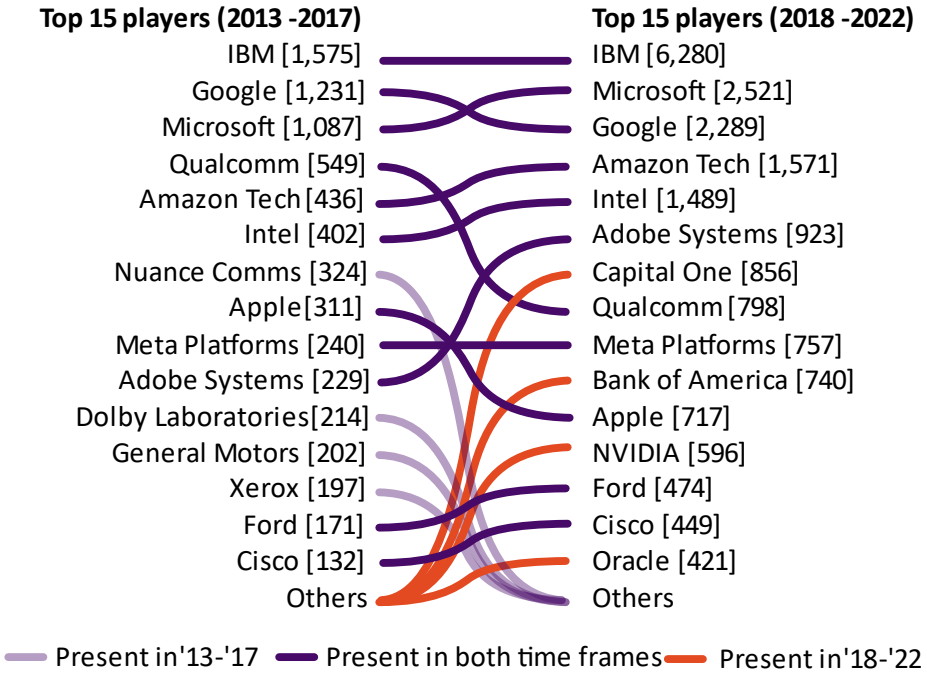
United States

The private sector is the cornerstone of AI leadership in the U.S., as shown by the profiles of its top players (**Exhibit 6**). 11 companies that excelled in the initial five-year period from 2013 to 2017 maintained their positions in the next five years, demonstrating the enduring influence of established leaders. Prominent examples include the "Big Five" technology giants: Google, Amazon, Microsoft, Meta, and Apple (GAMMA). Alongside these established leaders, new players have emerged in the last five years, marking a period of growth and presenting opportunities for both technology and non-technology companies. In the technology sector, notable strides have been achieved by NVIDIA and Oracle; while in the non-technology realm, entities such as Capital One and Bank of America have successfully entered the forefront of AI innovation.

[6] 国务院, *新一代人工智能发展规划*, 2017

NVIDIA, in particular, has successfully positioned itself as a key player in the global AI innovation scene. Recognising the emerging AI trend, the company has swiftly shifted its focus towards AI-related ventures, with the proportion of its AI inventions surging from 3% in 2017 to over 50% in 2021.[7] Concurrently, NVIDIA began adapting its GPUs for specialised AI computations. Capitalising on its first-mover advantage, NVIDIA currently commands over 70% of the AI chip market, earning a substantial quadrupling of revenue in the last two years.[8]

Exhibit 6: U.S.' top AI innovators: Early and current leaders



[7] See Annex C: Exhibit C-2 for NVIDIA's AI patenting trend

[8] Visual Capitalist, *Nvidia vs. AMD vs. Intel: Comparing AI Chip Sales*, 25 Aug 2023

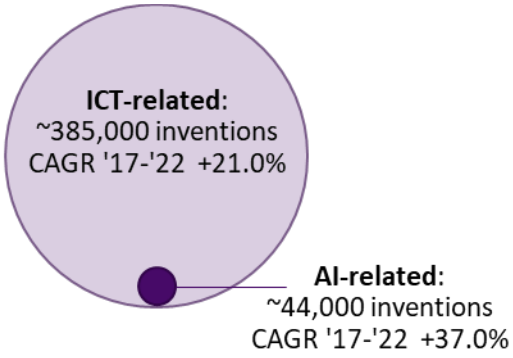
South Korea

AI has swiftly become integral in strengthening South Korea's leadership in Information and Communication Technology (ICT) (**Exhibit 7**). The South Korean government has shown a strong commitment to advancing digital capabilities, allocating 301.8 billion won for AI technologies and 1.02 trillion won for AI semiconductors from 2022 to 2026. This strategic allocation aims to position the nation as the world's third AI powerhouse, following China and the U.S.[9]

Prominent South Korean ICT companies like Samsung and LG are active innovators in AI. Samsung Electronics operates seven AI centres globally, focusing on various projects from algorithms to chip development. Specialised AI research centres have been set up in major universities to address the talent gap, with SKY universities (Seoul National University, Korea University, and Yonsei University) emerging among the top Korean AI innovators.[10]

South Korea strategically extends its ICT leadership to encompass AI.

Exhibit 7: South Korea's AI-related publications (top) and top innovators (bottom)



Top players in ICT	Top players in AI
Samsung Electronics [66,297]	Samsung Electronics [5,011]
LG Electronics [24,316]	LG Electronics [2,112]
Samsung Display [19,019]	Elect Telecom Research Inst [1,695]
LG Display [12,875]	Korea Adv Inst Sci Tech [929]
SK Hynix [9,189]	Seoul National Uni [773]

[9] Ministry of Science and ICT, *Korea Digital Strategy*, 27 Sep 2022
[10] See Annex C: Exhibit C-1 for full list of top AI innovators in South Korea

Canada

Canada, hailed as the birthplace of AI, has been instrumental in advancing AI. Distinguished figures like Geoffrey Hinton, Yoshua Bengio, and Richard Sutton have led the way in developing deep learning and reinforcement learning. The global recognition of Canada's AI achievements is evident in the international accolades received by its researchers, including the prestigious Turing Award.

Canada's emergence as a hub for AI innovation is evident in the formation of AI superclusters in Montreal, Toronto, and Edmonton (**Exhibit 8**). Strategically located near leading researchers, these clusters house premier institutions such as MILA, the University of Toronto, and the Vector Institute. These superclusters also attract companies, including major technology giants like Google, Huawei, Microsoft, and Facebook, who seek to establish research centres and collaborations, further solidifying Canada's standing as a hub for pioneering AI research.

Canada is advancing its position by building on a legacy of paradigm-shifting AI research.

Exhibit 8: Canadian AI research hubs and key AI players

Israel

Israel, renowned as the global hub of start-ups with the highest number per capita, has a rich culture of innovation and an efficient start-up ecosystem. AI represents a new frontier for technological progress in this entrepreneurial nation. Israeli AI entities often have modest portfolios. 95% of Israeli AI players have five inventions or fewer, indicating a sizeable number of small-scale start-ups (**Exhibit 9**). By embracing AI, Israel hopes to position itself as the third-largest hub for AI start-ups, behind the U.S. and China.[11]

Israeli start-ups exhibit diverse profiles and engage in a wide range of AI applications. These ventures frequently catch the eye of larger AI players, resulting in substantial acquisitions. For instance, Mobileye, which specialises in autonomous vehicles, was acquired by Intel for $15.3 billion. Habana Labs, which focuses on chip manufacturing, was acquired by Intel for $2 billion. Datorama, a marketing intelligence company, joined Salesforce in a transaction valued at $800 million. The trend continues with McKinsey's recent acquisition of Iguazio, an analytics platform provider, for $50 million.

Israel's start-ups are a major driving force in AI innovation.

Exhibit 9: Israel's top AI innovators (left) and AI players profile (right)

Top players
NICE [73]
Biosense Webster (Israel) [59]
Mazor Robotics [52]
Technion – Israel Institute of Technology[51]
OrCam Technologies [45]
Mobileye [44]
Given Imaging [41]
Ramot at Tel Aviv University [36]
BGN Technologies [35]
Verint Systems [34]

95% of Israeli AI players have 5 inventions or less, contributed by a high concentration of small-scale start-ups.

[11] Roland Berger and Asgard, *Artificial Intelligence – A strategy for European startups*, 2018

United Kingdom

The U.K. has established itself as a significant player in AI innovation, registering approximately 3,300 AI inventions, primarily driven by commercial entities (**Exhibit 10**). Leading global research institutions, such as Oxford University, Imperial College, and the University of Cambridge, contribute significantly to AI innovation. Other factors include abundant AI talent, the U.K. government's pro-innovation stance, and substantial funding commitments.

The U.K. has cultivated an environment conducive to AI companies, giving rise to notable entities such as DeepMind, Arm Holdings, and SwiftKey. These companies have contributed significantly to the AI landscape and have been strategically acquired by major corporations, including Google, SoftBank, and Microsoft. This underscores the U.K.'s significant impact on the global AI ecosystem.

The U.K. has established a nurturing environment for AI businesses, fostering growth and innovation.

Exhibit 10: U.K.'s AI players profile (top) and top AI innovators (bottom)

Commercial players	Research players
DeepMind [283]	Oxford University [76]
Cirrus Logic [158]	Imperial College [34]
BT [155]	University of Cambridge [32]
Arm Holdings [154]	King's College London [16]
Imagination Technologies [75]	Queen Mary University of London [14]
Jaguar Land Rover [58]	
Mercedes-Benz Group [33]	
Graphcore [32]	
Babylon Health [27]	
BAE Systems [26]	

Europe: Germany, Netherlands, Finland, Sweden, Denmark

European countries are using their robust industrial base to advance AI technologies, creating a distinct 'Made in Europe' identity. Key players cut across various industries, including automotive, manufacturing, electronics, and healthcare, strategically using AI to enhance Europe's global competitiveness and foster societal improvements (**Exhibit 11**). European governments actively support this innovation through dedicated national strategies and have united under the European Commission's initiative, AI for Europe, to develop human-centric and trustworthy AI applications.[12]

Europe strategically uses AI to secure industrial sovereignty and bolster its global technological standing.

In this ecosystem, German companies lead European AI innovation. With the government's plan to double AI funding to €1 billion over the next two years,[13] Germany aims to boost AI research and application in key industries. This effort seeks to reinforce Germany's competitive edge and contribute to Europe's leadership in the global AI landscape.

Exhibit 11: Top European players in AI and their industry sectors

Industry	Top players
Automotive	BMW - Bayerische Motoren Werke [337] Volkswagen AG [287] Daimler AG [283] Mercedes-Benz Group [280] Continental AG [245] Audi [222] ZF Friedrichshafen AG [210]
Manufacturing	Robert Bosch [1,498] Siemens AG [736] SAP SE [521]
Electronics	Philips [1,168] Nokia [722] Ericsson [652]
Healthcare	Siemens Healthineers [880]

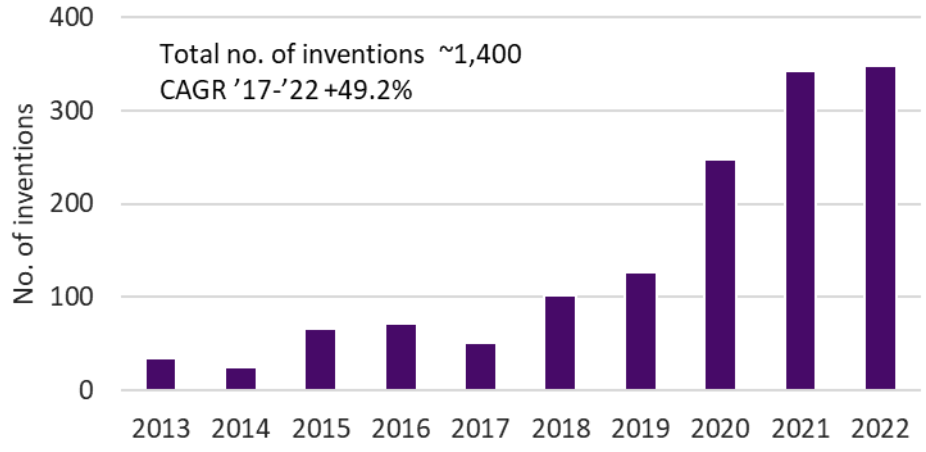
[12] European Commission, *Artificial Intelligence for Europe*, 2018
[13] Reuters, *Germany plans to double AI funding in race with China, U.S.*, 23 Aug 2023

Singapore

As a small nation lacking natural resources, Singapore understands the necessity of technological advancement to stay competitive globally. In this respect, AI has been identified as a vital component of growing Singapore's Digital Economy. Setting the foundation with the launch of AI Singapore (AISG) in 2017 – a S$150 million national program to deepen Singapore's AI capabilities for the future digital economy – the nation has formalised its aspiration to lead AI innovation with the release of Singapore's National AI Strategy in 2019. In alignment with its commitment to AI excellence, Singapore has recently launched the Singapore National AI Strategy 2.0 with the aim of developing AI for the public good in Singapore and beyond.

In the last decade, Singapore has registered nearly 1,400 AI inventions, boasting an impressive CAGR of 49.2% in the past five years (**Exhibit 12**). This growth, which exceeds the global average in AI patenting by almost 1.5 times, reflects Singapore's commitment to contribute to global AI development.

Exhibit 12: Singapore's AI patenting trend (top) and top AI innovators (bottom)



Top players

Lenovo (Singapore) [222]
BIGO Technology [190]
Alibaba Singapore [118]
SenseTime Singapore [74]
Agency for Science, Technology and Research A*STAR [73]
Nanyang Technological University NTU [67]
National University of Singapore NUS [66]
Sivantos [44]
Alipay Labs Singapore [37]
Smith+Nephew [29]

Singapore's research institutes are among the top innovators in AI, nurturing a rich pool of exceptional AI talent. Local universities Nanyang Technological University (NTU) and National University of Singapore (NUS), for example, were ranked among the top 20 organisations with the most-quoted AI-related research papers,[14] highlighting global recognition of the nation's AI capabilities. This strong foundation has attracted international businesses and collaborations, including the Dyson Technology Centre established in 2017, a joint AI research lab between Alibaba and NTU initiated in 2018, and the inauguration of SenseTime's AI Innovation Hub in Singapore in 2021. These partnerships enhance Singapore's global appeal as a hub for cutting-edge AI work and offer promising opportunities for local companies, as seen with BIGO Technology, a Singapore-based AI-powered broadcasting company that achieved unicorn status in 2019. BIGO's success shows the fertile environment for homegrown firms within the growing field of AI innovation.

To accelerate AI development in Singapore, the government has introduced several programmes and initiatives to build an extensive ecosystem. These include AI Makerspace and AISG's 100 Experiments Program, which support AI use in businesses, and the StartupSG program, which provides resources for promising start-ups. Singapore actively participates globally and collaborates with international partners. A notable example is the launch of the AI Verify Foundation, an alliance involving over 50 technology practitioners, including Google and Microsoft, to shape the future of international AI standards.

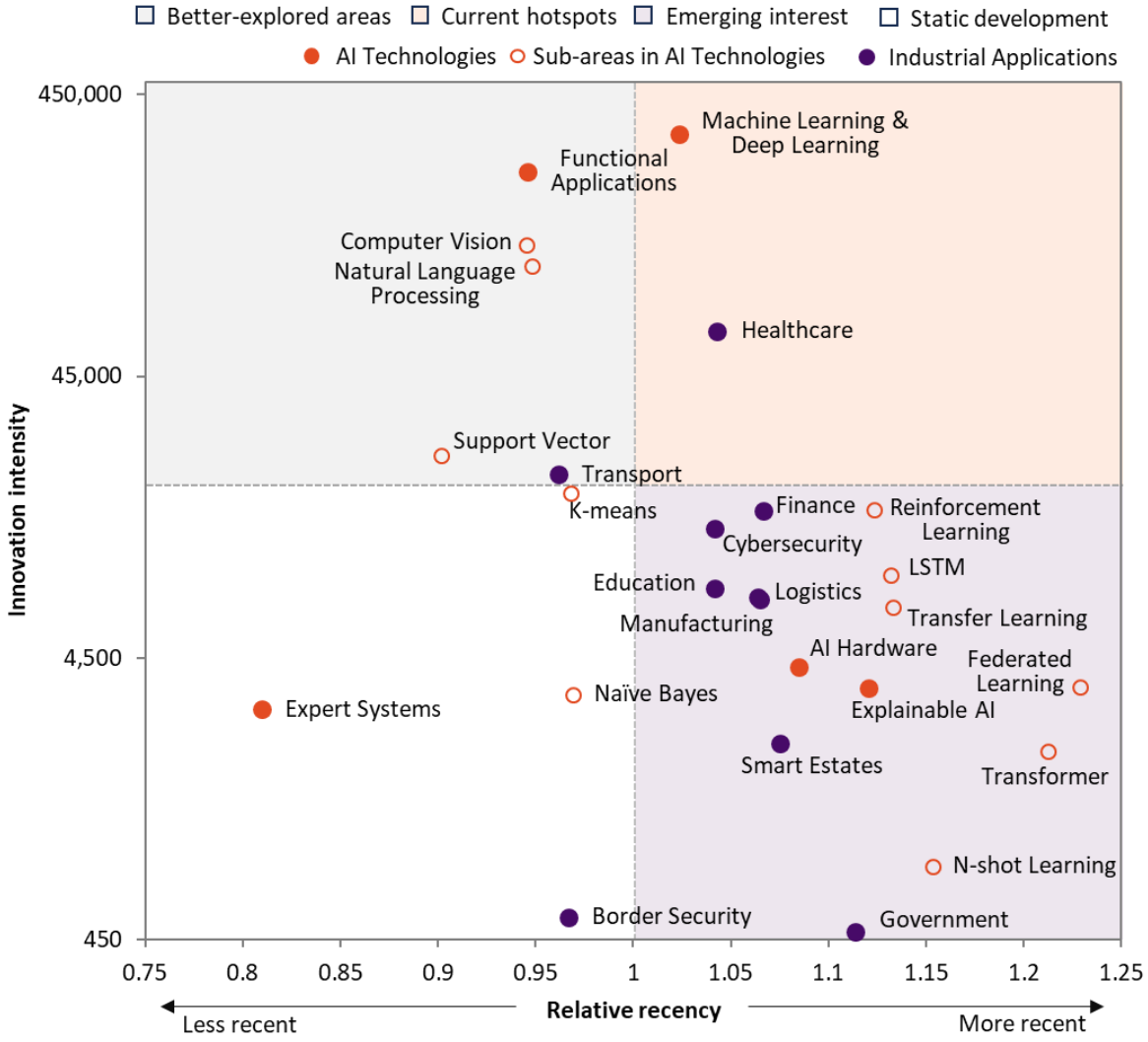
[14] Nikkei Asian Review, 2 Nov 2017

Current State of Innovations

By categorising the 680,000 AI-related inventions published in the past decade into their respective areas,[15] and calculating their recency – a measure of how recently the AI innovations were developed[16] – this report assesses the relative technology maturity of each AI area using an innovation maturity matrix (**Exhibit 13**).

Exhibit 13: Innovation maturity matrix of AI

The innovation maturity matrix helps identify current research hotspots and emerging areas.



[15] See Exhibit 1 for the hierarchical structure of areas

[16] See Annex A: Methodology

AI Technologies

AI technologies are at the heart of the innovation landscape, comprising the majority of inventions. This study delves into various AI technologies, including machine learning and deep learning, functional applications of AI, AI hardware, and explainable AI, and provides detailed examination and analysis.

Machine Learning and Deep Learning

Machine learning and deep learning serve as the foundational pillars, having been extensively explored with about 320,000 inventions over the last decade. About 50% of the overall AI dataset relates to the development and applications of these technologies and covers well-established techniques, such as neural networks, deep learning, clustering, regression models, ensemble learning, and decision trees (**Exhibit 14**).

Machine learning and deep learning stand as foundational forces in AI applications, with ongoing innovation directed towards crafting novel algorithms.

Despite significant technological advancement, machine learning and deep learning continue to be active innovation hotspots. The global AI community continues to pioneer innovative algorithms capable of tackling complex real-world problems. This ongoing evolution is evident in the emergence of advanced AI techniques, including reinforcement learning, long short-term memory (LSTM), transfer learning, federated learning, transformer, and N-shot learning. These techniques have exhibited remarkable growth, with the volume of innovation growing at least 16-fold from 2018 to 2022 compared to 2013 to 2017 and surpassing the fivefold growth of overall AI technologies (**Exhibit 15**).

Emerging AI technologies fall into two distinct categories. Reinforcement learning, LSTM, and transfer learning have achieved recent breakthroughs, building on their extensive histories of development. Meanwhile, federated learning, transformer, and N-shot learning represent novel AI technologies rapidly gaining traction. Transformer models, introduced in 2017, exemplify the ongoing evolution and introduction of cutting-edge AI technologies.

Exhibit 14: Breakdown of machine learning and deep learning technologies

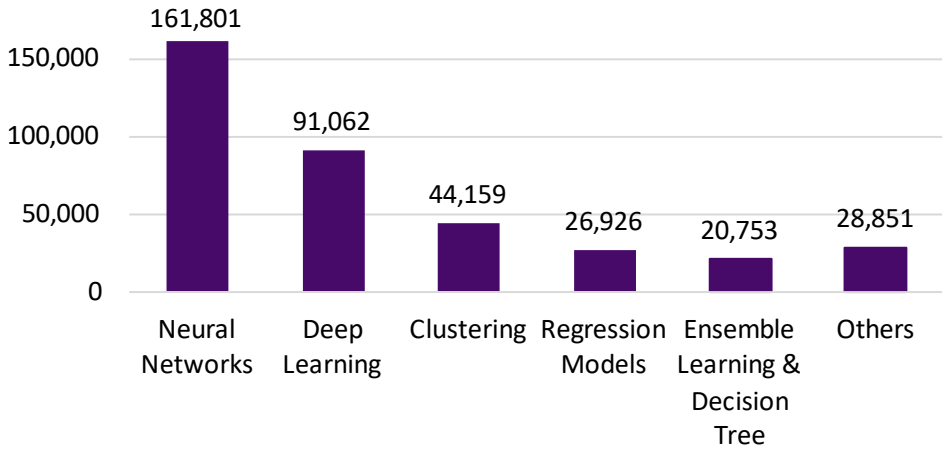
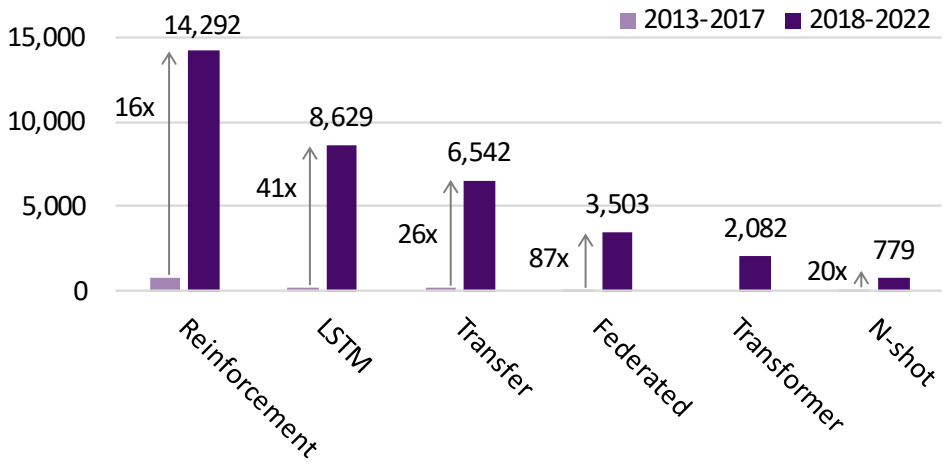


Exhibit 15: Innovation output of emerging AI technologies



Reinforcement learning is an iterative process rooted in experiential learning and relies on a reward-and-punishment system based on AI's actions. This approach has garnered widespread acclaim for its exceptional performance in games like Go, Chess, and Atari. In recent years, reinforcement learning has found diverse applications across industries, including streaming services. For instance, Netflix uses reinforcement learning to optimise user recommendations (patent application no. US10482519). In retail, Walmart uses reinforcement learning to automate price reduction suggestions for clearing unsold inventory (patent application no. WO2022/031269). In finance, IBM has developed an autonomous trading system trained through reinforcement learning (patent application no. US20200242449). In the automotive industry, exemplified by Volkswagen, reinforcement learning is used to simulate real-world scenarios for training autonomous vehicles (patent application no. US20210263526).

LSTM has gained strong attention for its effectiveness in handling sequential data, excelling in tasks such as time-series prediction and natural language processing. Notably, the State Grid Corp, a leading innovator with a portfolio of 399 LSTM inventions, has dedicated a significant portion (109 inventions) to leverage LSTM for industrial time-series power load forecasting.[17] Google has also demonstrated LSTM's efficacy with five inventions focused on speech recognition. **Transformer models** have emerged as a preferred option for various language-related applications, as they are particularly well-suited for large-language-model-based applications. These models are behind the success of chatbots that use language models, like ChatGPT.

Transfer learning and **N-shot learning** aim to address challenges associated with limited training data. Transfer learning involves adapting and applying a model learned from one task to another related task, while N-shot learning trains a model to classify objects based on a restricted number, N, of examples. These methods are especially useful for demanding tasks in natural language processing and computer vision [18] and address the issue of small training datasets in computer vision and natural language processing tasks, which is often due to difficulties in collecting enough data or the high cost involved.

Federated learning, introduced by Google in 2016, is a rapidly emerging AI technique with strong commercial potential. It involves training models using distributed datasets at the edge, which improves data privacy and security compared to centralised approaches. Led by commercial players,[19] innovations in federated learning enable collaboration among data owners without sacrificing control, addressing data privacy challenges and aligning with regulations like the Personal Data Protection Act. WeBank, a digital-only financial institution, has highlighted its use by transforming its financial offerings. However, as federated learning is still early in development, addressing challenges such as communication overhead, data heterogeneity, and cybersecurity is crucial for its progress across different industries.

[17] See Annex C: Exhibit C-3 for list of top innovators in LSTM and transformer

[18] See Annex C: Exhibit C-4 for breakdown of transfer learning and N-shot learning inventions by uses

[19] See Annex C: Exhibit C-5 for patenting trend of federated learning and its top innovators

Functional Applications of AI

Capitalising on a strong foundation in AI algorithms, functional applications of AI have experienced substantial growth. Specifically, computer vision and natural language processing have been extensively explored, accumulating large technology portfolios of about 131,000 and 110,000 inventions, respectively. This well-developed landscape in computer vision and natural language processing plays a crucial role in advancing industrial applications.

In computer vision, applications span a wide range of sectors. In healthcare, for instance, computer vision is used for medical image analysis, aiding in the detection of diseases and anomalies with unprecedented precision. The automotive industry uses computer vision for autonomous vehicles, enabling advanced driver assistance systems and improving road safety. In manufacturing, computer vision helps quality control and process optimisation, ensuring seamless production processes. In retail, computer vision powers innovative solutions like cashier-less stores, revolutionising the shopping experience for consumers.

Similarly, natural language processing is applied across diverse domains. In the financial sector, it streamlines document processing, sentiment analysis, and customer support, improving efficiency and decision-making. In education, natural language processing supports intelligent tutoring systems, personalised learning platforms, and automated assessment tools. Customer service has been transformed by chatbots and virtual assistants powered by natural language processing, providing instant and personalised assistance. Additionally, legal and compliance processes benefit from natural language processing applications for contract analysis and regulatory compliance checks.

AI Hardware

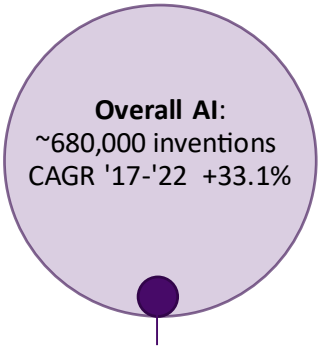
Unlike the extensive development of AI algorithms, AI hardware has only recently come into focus, with about 4,000 inventions registered in the past decade and an impressive CAGR of 57.9% from 2017 to 2022 (**Exhibit 16**). Innovations in this area are mainly led by a few commercial players, underscoring the early stage of this space and the strategic advantage enjoyed by early movers.

In AI hardware, a specific segment that has garnered significant attention is edge computing hardware. This sector has experienced remarkable growth, surging 187 times compared to the broader AI hardware landscape's 14-fold increase (**Exhibit 17**). This momentum is driven by the increasing prevalence of IoT solutions, especially in sectors like consumer electronics and autonomous vehicles, where data processing at the source is imperative.

AI hardware, particularly AI hardware for edge computing, is witnessing strong innovation growth.

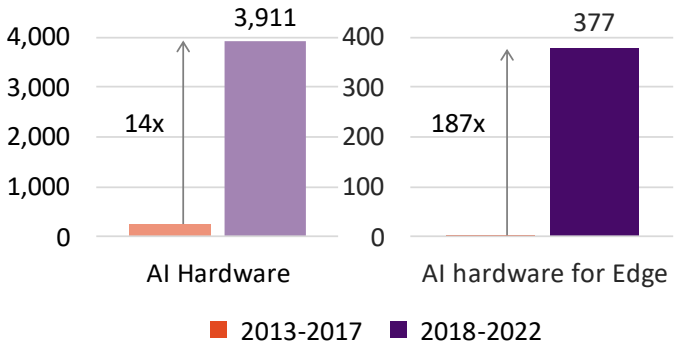
Edge computing offers benefits such as real-time processing, reduced latency, bandwidth efficiency, and heightened privacy and security. Although the sector is still in its early stages with about 400 inventions, established players in the broader AI hardware domain are exploring this specialised space. The presence of start-ups like DEEPX in South Korea and EdgeCortix in Singapore further underscores the potential of AI hardware for edge applications.

Exhibit 16: Global AI publications share relating to AI hardware (left) and top innovators (right)



Top players
Cambricon Technologies [236]
NVIDIA [127]
Samsung Electronics [126]
Micron Technology [120]
Intel [113]
Institute of Computing Technology, Chinese Academy of Sciences [81]
Tsinghua University [64]
IBM [62]
Huawei [54]
Oppo [51]

Exhibit 17: Comparison between AI hardware and AI hardware for edge (left) and top innovators (right)



Top players in AI hardware for Edge
NVIDIA [41]
Cambricon Technologies [22]
Intel [19]
Samsung Electronics [10]
DEEPX [6]
EdgeCortix [6]

Explainable AI

As AI becomes more prevalent across various sectors and industries, establishing trust is paramount for encouraging widespread AI adoption, especially in sensitive areas like healthcare and finance. However, despite its importance, explainable AI has received relatively less attention in innovation, with only around 3,500 related inventions published between 2013 and 2022 (**Exhibit 18**). This represents a small fraction within the broader AI technology field, as the focus on innovation has been more on result-oriented AI rather than explainable AI.

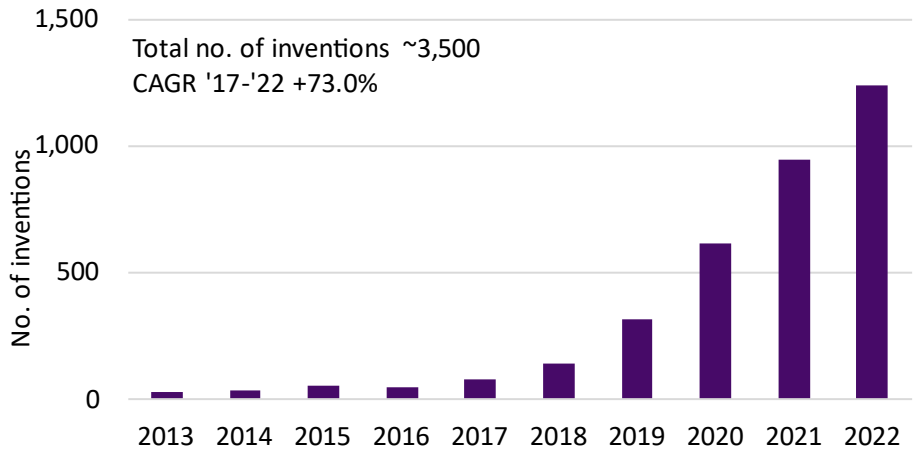
Despite modest innovation in explainable AI, its importance is underscored by the specific requirements of different applications. Certain applications, such as image recognition, prioritise high accuracy, whereas others like medical diagnosis demand both accuracy and interpretability. Striking a balance between explainability and performance is crucial to meeting diverse application needs and ensuring the responsible use of AI.

Explainable AI is an emerging field crucial to meeting the specific requirements of various applications.

Efforts to develop explainable AI involve collaboration between research institutes and commercial players. Both groups bring their expertise to develop the technology, with research players excelling in algorithmic development and explainability techniques, and commercial players providing practical insights into real-world challenges.

The industry further benefits from open-source tools developed by technology giants and the research community. Some examples include AIX360 by IBM, InterpretML by Microsoft, LIT by Google, AllenNLP Interpret by the Allen Institute for AI, Captum, TensorBoard, and Skater. IBM's recent release of watsonx.governance, a commercial product for enterprises, represents a significant step towards promoting the responsible use of AI in the industry.

Exhibit 18: Patenting trend of explainable AI (top) and top AI innovators (bottom)



Top players

IBM [103]
Zhejiang University [57]
Tsinghua University [52]
Xi'an Jiaotong University [41]
Ping An Technology [40]
Tencent [32]
University of Electronic Science & Technology of China [30]
Beijing University of Aeronautics and Astronautics [28]
Google [27]
Beijing University of Technology[21]

Industrial Applications

Built on a solid foundation of technology advancement, AI is now beginning to make its mark across various industries. Its applications span a broad range of sectors, including healthcare, finance, cybersecurity, transport, logistics, manufacturing, education, smart estates, border security, and government.

Exhibit 19: Country-level innovation specialisation across industries

The number in the table refers to a country's specialisation index, measured by the proportion of AI inventions in the area over the total number of AI inventions originating from the nation.

	China	U.S.	South Korea	Germany	U.K.	Canada	Netherlands	Israel	Singapore	Sweden	Finland	Denmark
Education	1.2%	0.5%	2.8%	0.1%	0.3%	0.4%	0.1%	0.3%	0.9%	0.1%	0.5%	0.6%
Healthcare	7.7%	14.7%	10.7%	15.9%	15.2%	18.4%	47.4%	24.8%	10.8%	8.8%	8.7%	19.3%
Finance	2.1%	3.3%	2.5%	0.4%	1.8%	4.4%	0.5%	2.7%	3.5%	0.4%	0.3%	0.6%
Cybersecurity	1.6%	4.1%	1.3%	1.5%	4.9%	2.5%	0.9%	8.0%	2.1%	2.8%	2.7%	0.3%
Transport	1.4%	4.3%	6.1%	17.1%	4.5%	3.5%	1.9%	4.5%	1.2%	8.3%	1.3%	0.9%
Logistics	0.8%	2.0%	1.2%	1.4%	1.3%	1.8%	0.4%	1.5%	2.1%	1.0%	0.9%	1.8%
Manufacturing	0.9%	0.9%	1.1%	2.7%	0.7%	1.0%	2.0%	2.1%	1.1%	0.6%	0.7%	1.2%
Smart Estates	0.4%	0.0%	0.1%	0.1%	0.2%	0.3%	0.1%	0.1%	0.1%	0.0%	0.0%	0.0%
Border Security	0.1%	0.1%	0.1%	0.4%	0.6%	0.2%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%
Government	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Globally, the healthcare sector stands out as the primary focus of AI innovation, garnering unmatched attention from countries worldwide. (**Exhibit 19**). For example, nearly half of AI inventions in the Netherlands and a quarter in Israel are dedicated to advancements in healthcare. Remarkably, it is the singular industry uniformly prioritised in the AI strategies and policies of all nations.[20] This interest is fuelled by the rising demands of an ageing population and a heightened awareness of evolving healthcare needs.

Healthcare emerges as the foremost industry in AI application interest globally; finance, cybersecurity, and transport sectors capture the interest of countries.

Beyond healthcare, countries are directing targeted innovation efforts toward specific industries. The finance sector, for example, is a focal point in China, Canada, and Singapore, while cybersecurity gains strategic emphasis in the U.S., U.K., and Israel. The transport sector receives special attention from Germany, Sweden, and South Korea. These concentrated efforts reflect the diverse global landscape of AI applications, with countries aligning their innovation priorities with industry needs.[21]

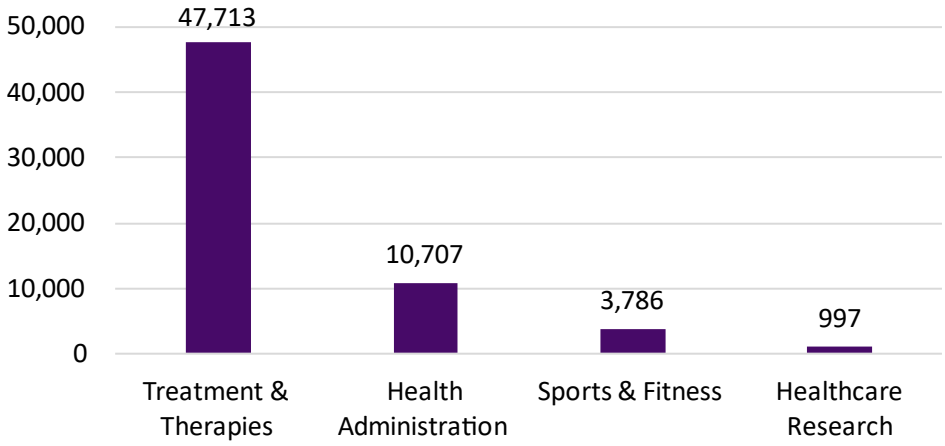
[20] OCED Going Digital Toolkit, *An overview of national AI strategies and policies*, 2021
[21] See Annex C: Exhibit C-6 to C-12 for country rankings (based on no. of inventions) and top innovators in respective industries

Healthcare

Over the past decade, more than 65,000 healthcare-related AI inventions have been registered. This shows an increased interest in the use of AI in diverse healthcare cases that focus on treatment and therapies, as well as health administration (**Exhibit 20**). This application addresses the global shortage of healthcare workers, estimated at 10 million workers by 2030.[22] Applications in sports and fitness and healthcare research are on the horizon. Notably, healthcare research is in its infancy, marked by the world's first AI-generated drug, Insilico Medicine's INS018_055, which began human trials in June 2023.

Established AI technologies are becoming increasingly vital in healthcare (**Exhibit 21**). Machine learning and deep learning, as predominant techniques, are versatile, aiding in tasks like computer-aided disease diagnosis, personalised treatment plans, workflow optimisation, real-time tracking and monitoring, and drug design simulation. Natural language processing is crucial for documentation, health records analysis, and patient communication using conversational agents. Computer vision, especially in medical imaging, is key for diagnostics. This comprehensive use shows AI's transformative impact on healthcare challenges and advancing medical capabilities.

Exhibit 20: Breakdown of AI in healthcare inventions by innovation areas



[22] World Health Organization, *Global Strategy on Human Resources for Health: Workforce 2030: Reporting at Seventy-fifth World Health Assembly*, 2 June 2022

Exhibit 21: Breakdown of AI technologies by healthcare innovation areas

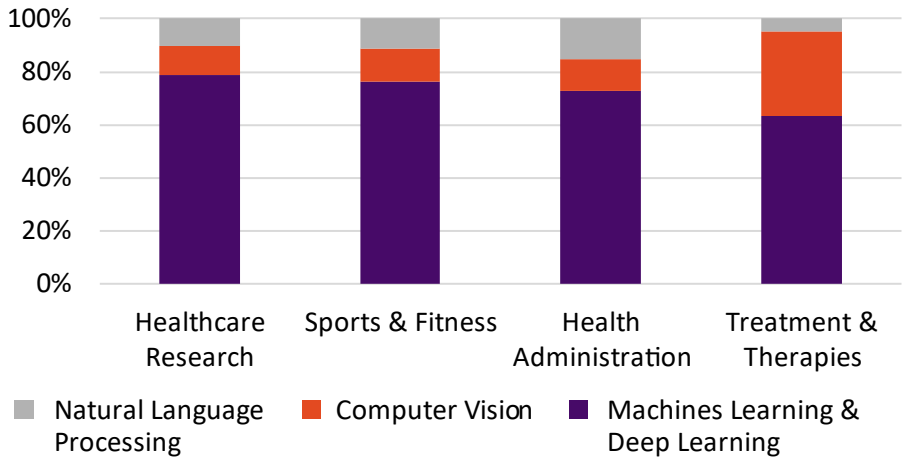


Exhibit 22: Top healthcare AI innovators

Healthcare Research	Sports & Fitness
Merative [21]	Philips [44]
IBM [18]	IBM [35]
Vignet [14]	Samsung Electronics [31]
Fudan University [14]	Fitbit [19]
Nanjing Uni Posts Telecom [10]	Zhengzhou University [19]
Central South University[10]	Microsoft [16]
Recursion Pharmaceuticals [7]	Tata Consultancy Services [16]
Exscientia [7]	Lovely Professional University[15]
Stanford University [7]	Nike [14]
Insilico Medicine [6]	Zhejiang University [14]

Healthcare Administration	Treatment & Therapies
Philips [261]	Siemens Healthineers [875]
Ping An Technology [188]	Philips [802]
IBM [150]	Ping An Technology [564]
Siemens Healthineers [148]	IBM [513]
Ping An HealthKonnect [129]	Zhejiang University [387]
Ping An Good Doctor [85]	United Imaging Healthcare [379]
Canon Medical Systems [75]	Fujifilm [332]
Merative [69]	Shenzhen Inst Adv Tech [284]
Cerner [61]	Canon Medical Systems [257]
Baidu [59]	Tsinghua University [252]

Despite significant technological progress, AI's potential in healthcare is still in its early stages, as evidenced by the profile of top innovators (**Exhibit 22**). The landscape lacks dominant players, presenting a mix of multinational corporations, new entrants, start-ups, and research entities across all areas. This environment is characterised by increasing merger and acquisition activities, as seen in Siemens Healthineers' acquisitions (e.g., ECG Management Consultants in 2019, Varian Medical Systems in 2021, and Aspekt Solutions in 2023) under its Strategy 2025 plan focusing on AI. In 2023, NVIDIA invested $50 million in Recursion Pharmaceuticals for AI drug discovery. This dynamic landscape presents opportunities for further development.

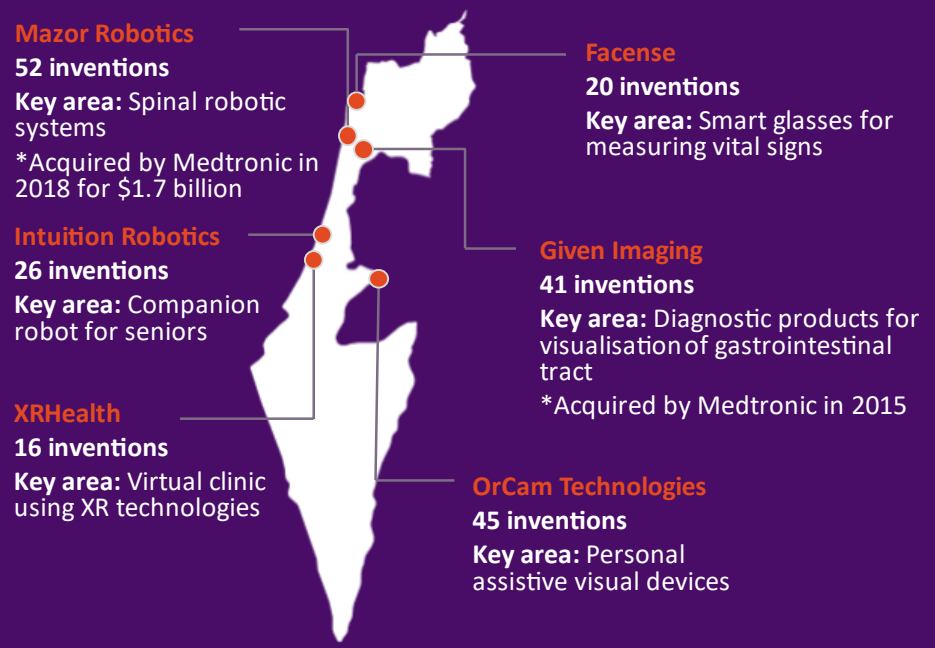
AI for healthcare is in its early stages, with opportunities for further development.

Healthcare Spotlight: Israel

Israel's innovation prowess is well-known, backed by the government's focus on critical sectors. After successes in cybersecurity and autonomous vehicles, Israel has identified digital health as the next economic growth frontier. This plan was unveiled in 2018, with a budget of USD$300 million to drive development in the digital health sector. Notably, AI-based digital health companies in Israel have attracted substantial investments, comprising almost 85% of total investments in the digital health sector.[23] Israel has also launched Project Mosaic, which aims to establish a nationwide genome database to advance research and personalised medicine.

With robust government support, Israeli companies are active contributors to the healthcare and life sciences landscape. Israel is home to 1,500 healthcare and life sciences companies, making it the second-largest hub globally, surpassed only by the U.S. [24] These companies are involved in various applications in the healthcare sector, including surgical robotics, diagnostic tools, teleconsultation, wearables and companion robots (**Exhibit 23**). A common trend in this ecosystem is the acquisition of companies with strong potential by larger players, further shaping the evolving healthcare and life sciences sector in Israel.

Exhibit 23: Top AI healthcare innovators in Israel



[23] Statista, *Investments in the digital health sector in Israel from 2014 to 2018*
[24] Calcalist, *Innovation in healthcare technology is setting Israel up as a global powerhouse*, 2 Dec 2020

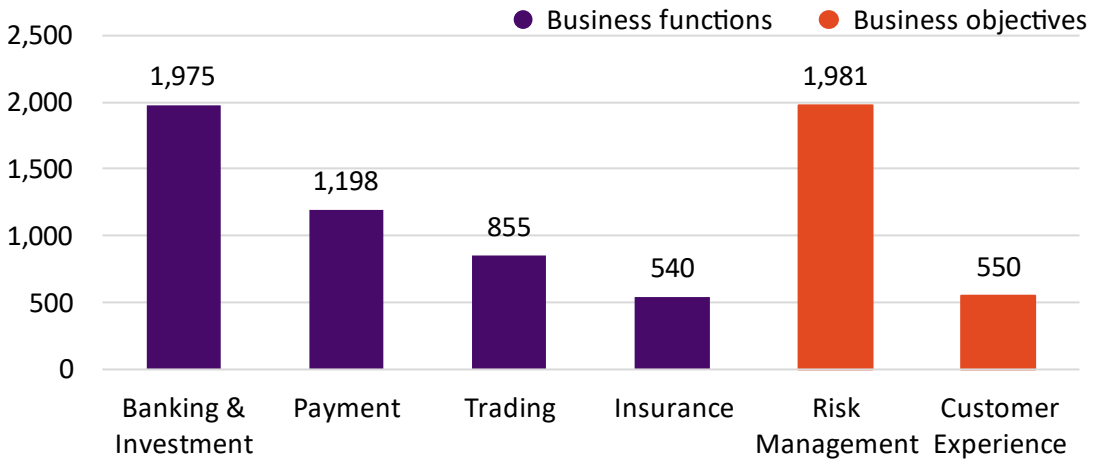
Finance

The finance sector, known for managing substantial transaction volumes and funds daily, is always looking for innovative solutions to boost operational efficiency and minimise errors. The adoption of AI in the finance sector has gained strong traction, with nearly 15,000 inventions registered in the past decade (**Exhibit 13**). Banking and investment, and payment processes stand out as the primary business functions (**Exhibit 24**), crucial for day-to-day mass-market operations involving extensive data handling and processing. AI plays a central role in automation, thereby enhancing efficiency.

However, the finance sector grapples with persistent challenges, such as large losses to fraud yearly. Risk management remains a significant concern. Financial institutions now also recognise customer experience as an important business focus and are prioritising superior services to build customer loyalty.

An exemplary example of providing seamless customer experiences is Ping An. Ranked 25th on the 2022 Fortune Global 500 list and 4th among global financial enterprises, Ping An has subsidiaries in insurance, banking, and asset management, each with significant technology expertise. For instance, Ping An Technology boasts 334 inventions, Ping An Property Insurance has 105 inventions, and Ping An Bank has 100 inventions. By adopting an integrated financial model, Ping An encourages customers to buy multiple products across its subsidiaries, promoting customer retention. Beyond finance, Ping An strategically leverages synergies between its financial and healthcare businesses, ensuring a smooth customer experience across both sectors.

Exhibit 24: Breakdown of AI in finance inventions by innovation focus



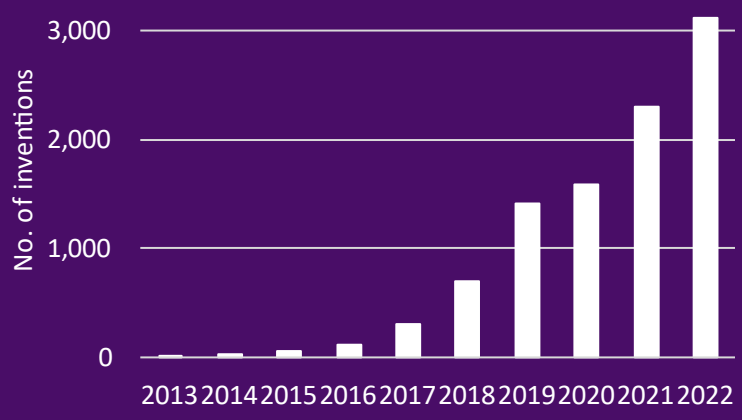
Finance Spotlight: China

China leads the way in financial technologies, driven by the need to provide banking services to people in remote areas without access to traditional banking services, including ATMs. Recognising the importance of universal financial access for societal progress, the world's second-largest economy has used its highly connected population and digital infrastructure to achieve financial inclusion goals. The nation's 2016-2020 financial inclusion plan focuses on digital technologies, capitalising on widespread internet connectivity.[25] This has led to an increase in the use of AI in finance, where the number of AI-related inventions has grown over 200 times, from 15 in 2013 to 3,129 in 2022 (**Exhibit 25**). The result is the development and widespread adoption of innovations such as mobile payments, digital wallets, and online financial services.

This push towards digitalisation also attracts major tech players like Alibaba, Tencent, and Baidu into the financial sector, leading to a wide array of tech-driven financial products. Notable examples include Alibaba's mobile payment business Alipay, Tencent's digital-only banking service provider WeBank, Ping An's technology-as-a-service financial platform OneConnect, and Baidu's fintech arm Du Xiaoman. This distinctive trend sets China apart from other countries, where a strong presence of traditional banks and financial institutions often dominates the finance sector.

Exhibit 25: Patenting trend of China's AI inventions in finance (left) and top innovators (right)

China's AI inventions in finance have grown 200 times from 15 in 2013 to 3,129 in 2022.



Top Chinese players

Bank of China [1,036]
Ind Commercial Bank China [930]
Ping An Tech [334]
China Construction Bank [229]
WeBank [205]
OneConnect [165]
Alipay [149]
Tencent [111]
Ping An Property Insurance [105]
CCB Fintech [104]

[25] 国务院, *推进普惠金融发展规划 (2016-2020 年)*

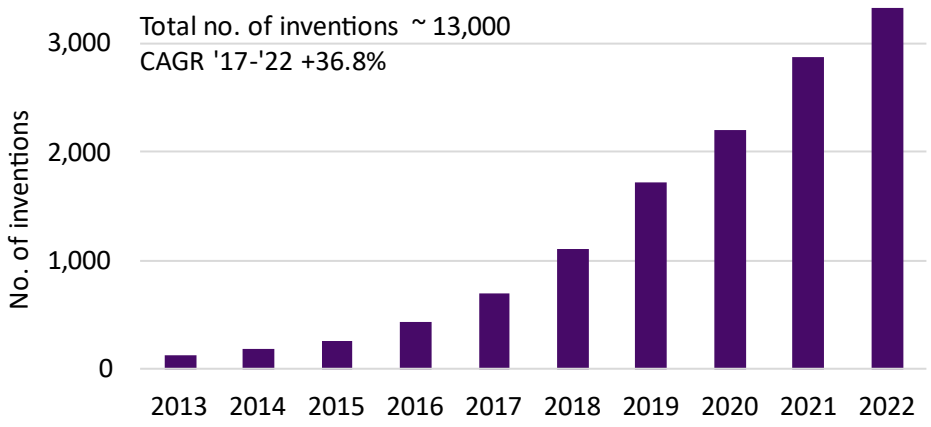
Cybersecurity

The surge in digitalisation and interconnectivity has transformed how we conduct business, communicate, and manage information. However, it has also increased our vulnerability to cyber threats. Instances of malware, including computer viruses, trojans, spyware, ransomware, adware, worms, file-less malware, and hybrid attacks, have spiked from 12.4 million in 2009 to 812.67 million in 2018[26] – a staggering 65-fold increase.

The convergence of AI and cybersecurity is a crucial frontier for fortifying digital defences. The growing use of AI in cybersecurity is apparent, with about 13,000 inventions recorded in the past decade (**Exhibit 26**). AI complements existing cybersecurity frameworks by enabling the swift processing of large data volumes and automating analytical processes. Notable use cases include real-time threat detection, malware analysis, and threat hunting. The integration of AI in cybersecurity also serves as a strategic response to the global shortage of cybersecurity talent.

As AI strengthens security measures for defenders, it also equips cybercriminals with advanced tools to exploit vulnerabilities more effectively. This dual role of AI poses challenges for both sides and intensifies the complexity and challenges within the ever-evolving cybersecurity landscape. In this fast-paced environment, where cyber threats grow increasingly sophisticated, ongoing monitoring and adaptation to emerging technologies are essential.

Exhibit 26: Patenting trend of AI in cybersecurity



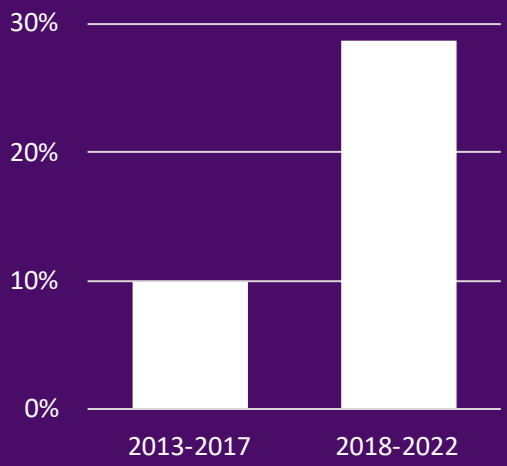
Cybersecurity Spotlight: U.S.

The U.S. ranks among the world's top digital economies, consistently securing a leading position since 2017, according to the IMD World Digital Competitiveness Ranking. The nation has fortified its cybersecurity capabilities to support its robust digital economy, strategically integrating AI into cybersecurity practices. Over the years, there has been a significant rise in the proportion of U.S. cybersecurity inventions incorporating AI, growing from 10% in 2013 to 2017 to nearly 30% in 2018 to 2022 (**Exhibit 27**). This upward trajectory shows the nation's commitment to using AI-enhanced cybersecurity measures to protect its digital infrastructure and proactively address emerging challenges.

Along with the surge in AI-enhanced cybersecurity innovations, the U.S. has implemented initiatives to foster further development and widespread adoption. One such initiative is the AI Cyber Challenge (AIxCC), a two-year competition inaugurated by the U.S. government in August 2023 that uses AI to safeguard the nation's most critical software. Managed by the Defense Advanced Research Projects Agency (DARPA) and in collaboration with leading AI companies such as Anthropic, Google, Microsoft, and OpenAI, the competition offers nearly $20 million in prizes.

Elsewhere in the U.S., North Dakota has partnered with cybersecurity vendor Palo Alto Networks to deploy an autonomous security operations centre, using AI to manage low-level and less-threatening incidents. This approach allows human analysts to focus on higher-priority cyber protection and response tasks. Together, these initiatives showcase the U.S.' commitment to harnessing the power of AI to enhance cybersecurity practices and resilience.

Exhibit 27: Percentage of U.S. cybersecurity inventions using AI (left) and top innovators (right)



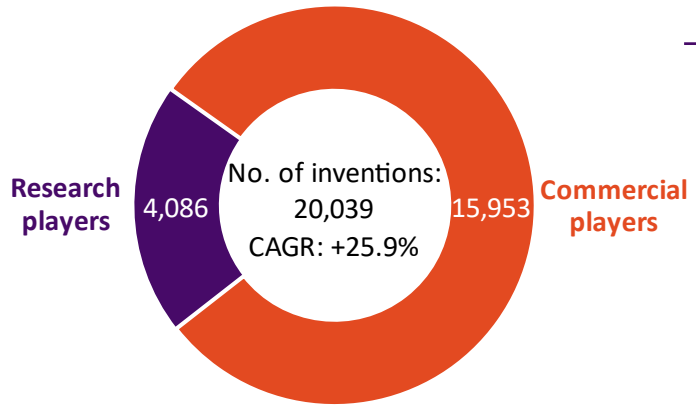
Top U.S. players
IBM [231]
Microsoft [178]
Cisco [120]
Bank of America [107]
Intel [75]
JPMorgan Chase Bank [65]
CA Technologies [62]
Cylance [50]
Google [49]
Qualcomm [42]

Transport

The transport sector has been a trailblazer in adopting AI, with over 20,000 inventions in the past decade. These innovations in AI aim to improve operational efficiency and enable autonomous driving. Compared to other sectors, AI in transport is more developed, with many inventions published in earlier years (**Exhibit 13**).

The transport sector, especially in the automotive industry, is fiercely competitive and dominated by commercial players (**Exhibit 28**). Automotive industry leaders are embracing AI to stay ahead and meet changing consumer needs. This shift is evident in the emergence of new business models, such as self-driving vehicles with features like auto surrounding analysis, collision avoidance, and autonomous navigation. AI is also boosting productivity by streamlining production processes and improving overall quality and efficiency through automated defect identification. AI is even enhancing the vehicles directly, with applications in predictive maintenance, vehicle optimisation, driver assistance systems, and driver fatigue detection.

Exhibit 28: Breakdown of AI in transport inventions by players profile (left) and top innovators (right)



Top players
Toyota Motor [682]
Denso [502]
Hyundai Motor [414]
LG Electronics [400]
Ford [400]
Honda Motor [341]
Robert Bosch [324]
General Motors [265]
Daimler AG [213]
Kia Motors [198]

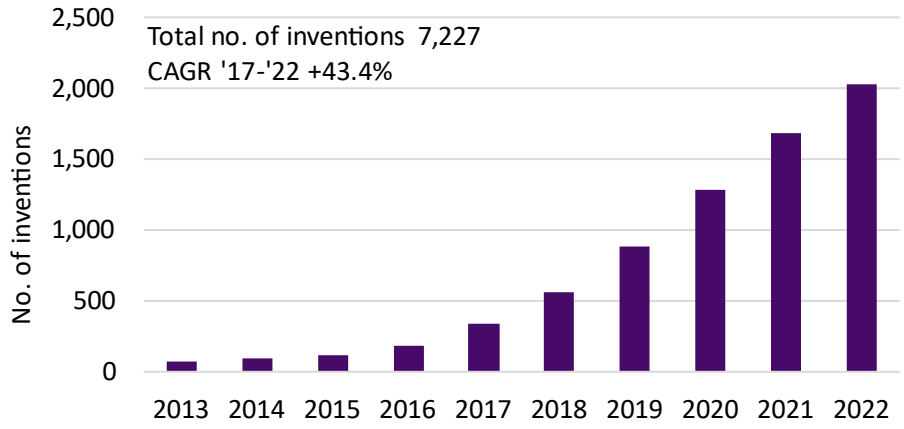
Logistics

The logistics sector is leveraging innovative technologies, especially AI, to drive advancements (**Exhibit 29**), given a growing interest in using AI to boost operational efficiency and cut costs. Key applications include AI-powered warehouse robots, tracking and predicting demand, optimising inventory management, and improving order processing capabilities.

E-commerce is an important catalyst for the transformation of the logistics sector worldwide, with top innovators such as Jingdong, Cainiao (Alibaba's logistics arm), Amazon, Coupang, and Shopify actively strengthening their positions through substantial patent portfolios.[27] This impact is global, and requires the establishment of efficient and extensive networks capable of handling the complexities of international shipping and delivery. Logistics providers must adapt and scale their operations to meet the evolving demands of a globalised e-commerce landscape.

Cainiao, a key player in the global e-commerce scene, illustrates this shift. Positioned at the heart of China's e-commerce ecosystem, Cainiao handles an impressive 70% of parcel deliveries within the country. Despite surging orders, the company remains focused on timely deliveries — ensuring parcels reach any location within China in 24 hours and globally in 72 hours. This success is due to Cainiao's commitment to innovation, particularly in the areas of smart logistics and AI, and its robust technology portfolio, which features 119 inventions.

Exhibit 29: Patenting trend of AI in logistics



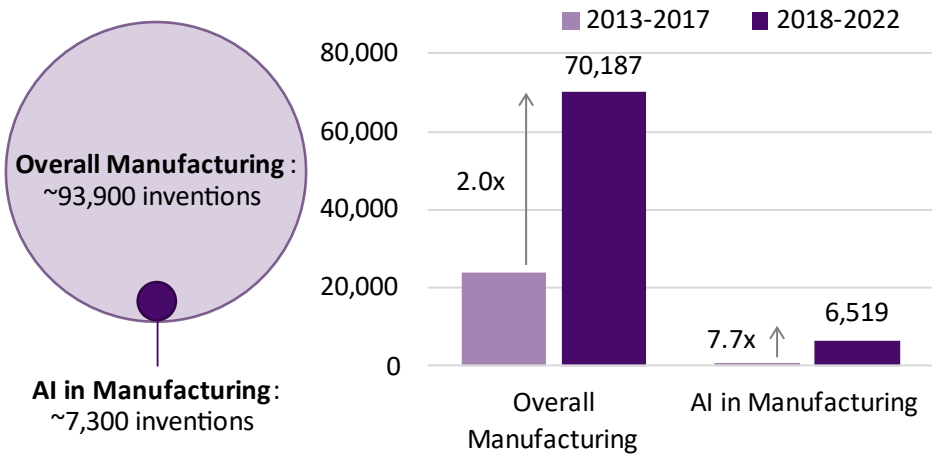
[27] See Annex C: Exhibit C-10 for list of top AI innovators in logistics

Manufacturing

The use of AI in the manufacturing sector is still in its early stages, representing less than 10% of overall innovations within the industry (**Exhibit 30**). Yet, this sector is ripe for AI adoption, thanks to the rise of industrial IoT and smart factories, which generate massive amounts of data, perfect for implementing AI technologies. Interest in AI for manufacturing has surged, growing 7.7 times from 2013-2017 to 2018-2022. Key applications include the integration of robotics, quality control facilitated by computer vision inspection, predictive maintenance, and product planning and optimisation, among others. This growing momentum reflects the potential of AI to revolutionise manufacturing.

Siemens AG, a global leader in industry, has long been a driving force in technology and innovation by advancing industrial digitalisation across sectors like energy, healthcare, and industrial automation. In manufacturing, Siemens has been particularly impactful, publishing a noteworthy total of 1,227 inventions between 2013 and 2022. These inventions span various themes, prominently featuring AI in manufacturing, automation, simulation, and digital twin technologies. The company's efforts have earned it prestigious accolades, including recognition in the 2023 Time100 Most Influential Companies for its outstanding contribution to digitalising factories. Siemens has also been named one of the 2023 Fast Company's top 10 most innovative companies in manufacturing, further solidifying its reputation as an industry trailblazer.

Exhibit 30: Global manufacturing publications share relating to AI in manufacturing (left) and innovation output of manufacturing (right)

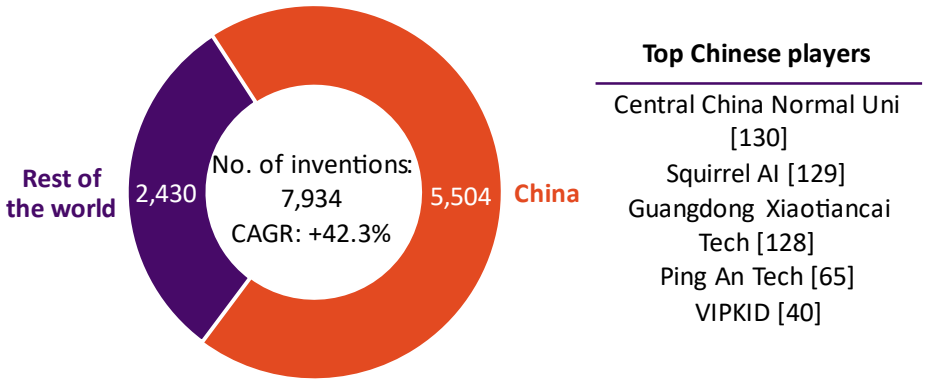


Education

The use of AI in education, an industry traditionally known for its emphasis on human interaction, is in its early stages, with about 8,000 inventions recorded in the last decade (**Exhibit 13**). Notably, China leads innovation in this field, contributing to nearly 70% of the total innovations (**Exhibit 31**). Both the penetration rate and market size of AI adaptive learning are projected to grow significantly to 19% and RMB 100 billion, respectively, by 2025.[28] Accompanying the societal emphasis on education excellence is a vibrant education technology (edtech) scene. China has the most active edtech market globally, with Chinese start-ups securing over 50% of venture capital investments in edtech worldwide in 2018.[29] This robust ecosystem has given rise to various unicorns, such as Squirrel AI and VIPKID.[30]

Squirrel AI, in particular, stands out as a prominent player with an extensive patent portfolio of 129 inventions. Leveraging advanced machine learning algorithms, the platform provides personalised educational solutions for K-12 students. The company has also collaborated with esteemed research partners, including the Institute of Automation (Chinese Academy of Sciences), Carnegie Mellon University, and Stanford Research Institute. The company's dedication to innovation is highlighted by multiple accolades, including a feature in the 2020 CB Insights AI 100 List as The Best AI Education Company.

Exhibit 31: Breakdown of AI in education inventions by players profile (left) and top Chinese innovators (right)



[28] Ernst & Young, *Intelligent beyond imagination, adaptive to the future – China AI adaptive learning industry whitepaper*, 27 Apr 2021
[29] Forbes, *Why Is China The World's Leader In Edtech?*, 5 Apr 2019
[30] See Annex C: Exhibit C-12 for list of top AI innovators in education

Conclusion

AI is a transformative technology of the 21st century, attracting strong innovation interest worldwide. Intensive research efforts have yielded numerous innovations that are shaping the global technology landscape.

China and the U.S. are the frontrunners in AI innovation, jointly accounting for almost 80% of global AI innovation. China's progress in AI development is primarily driven by government initiatives, while the U.S. relies on the private sector playing a leading role in fueling AI innovation. At the same time, other nations leverage their unique strengths to develop tailored AI ecosystems to secure a competitive advantage.

AI technologies are the backbone of the innovation landscape, representing the majority of inventions. Established techniques in machine learning and deep learning, along with practical applications in computer vision and natural language processing, provide the groundwork for diverse applications.

In contrast, AI hardware and explainable AI are emerging areas. AI hardware is being advanced to support software implementation and applications. The adoption of AI is guided by balancing explainability and performance to ensure its responsible use in various applications.

The application of AI across industries is just beginning to unfold, with healthcare emerging as the primary focus due to universal challenges such as ageing populations and the need for adaptive healthcare solutions. Beyond healthcare, targeted innovation efforts in finance, cybersecurity, and transport reflect a strategic approach to harnessing AI, aligning with specific national interests and industry needs.

As AI continues to transform industries, the strategic alignment of innovation efforts with sector-specific needs becomes increasingly crucial. The evolution of AI is ongoing, with each development bringing the global community a step closer to unlocking its full potential.

Annex A: Methodology

Dataset

The final dataset relating to AI was retrieved on 26 July 2023. The dataset consists of related patent applications published worldwide from 2013-2022.

Search string

To ensure optimal recall and accuracy of the dataset retrieved, the search strings used in this study were formulated incorporating keywords (and their variants) and patent classification codes and indexing, e.g. International Patent Classification (IPC) and Cooperative Patent Classification (CPC). Detailed lists of the main keywords and the patent classification codes used are presented in Annex B.

Grouping by patent family

The innovation intensity, i.e. the no. of inventions, in this study is measured by counts of patent families. A patent family is a group of patents related to the same invention. Analyses based on unique patent families reflect the innovation output more accurately; considering individual patent applications will inevitably involve double counting as a patent family may contain several patent publications if the applicant files the same invention for patent protection in multiple destinations.

In this study, the representative of a patent family, i.e. an invention, is chosen to be the earliest published family member.

Data cleaning

Systematic data cleaning and manual review were carried out to

1) remove non-patent specifications, e.g. utility model, and
2) ensure the relevance of the dataset prior to carrying out the analyses.

Refinement of the applicant field

IPOS International's in-house proprietary patent data cleaning platform and automated algorithms from commercial tools were used to refine applicants' information, e.g. by removing various spelling and punctuation mark discrepancies. The refined results were manually checked for accuracy.

Grouping of technology domain and areas

Grouping of patent families of the retrieved dataset into the respective technology domains and areas was carried out based on patent classification codes, text-mining and semantic analysis of the patent specifications, in particular, the titles, abstracts, and patent claims, as well as a manual review of the individual patent applications.

Recency

Recency used in this study measures quantitatively how recently the technologies were published (developed). It is calculated by a weighted average of the inventions whereby a higher weightage is given to inventions published in more recent years.

Formula

$$\overline{R} = \frac{\sum_{i=1}^{n}(w_i \times i)}{n \times \sum_{i=1}^{n} w_i}$$

where
i = 1 for the first year of the survey period, and *i* increases by 1 for every subsequent year in chronological order.
n = total no. of years of the survey period, and
w_i is the no. of inventions published in the year.

Relative recency

Relative recency in this study refers to normalised recency by taking the recency of the entire AI dataset to be 1.

Annex B: Search string

AI

Main keywords used

- artificial intelligence, machine learning, supervised learning, unsupervised learning
- (neural, Hopfield, feedforward, kohonen, self-organising, recurrent, echo state, siamese) **and** network, backpropagation, perceptron, autoencoder, neural radiance field, learning vector quantisation, ANFIS, neuro-fuzzy inference
- (deep, depth, residual, deep belief, adversarial, generative) **and** (learning, network, model), convolutional neural network, long short-term memory, LSTM, deep boltzmann machine, generative adversarial network, generative AI
- (linear, non-linear, logistic, polynomial, multi-variate adaptive, local, moving, non-parametric, kernel, kernel ridge, segmented, piecewise, least square, ridge, lasso, least-angle, elastic net) **and** regression, regression **and** (analysis, algorithm, model), scatterplot smoothing
- bayesian, bayes, averaged one-dependence estimators, AODE
- (instance-based, memory-based, locally weighted, lazy) **and** learning, k-nearest neighbour, kernel **and** (machine, method), support vector machine, radial basis, RBF **and** (network, learning)
- k-means, (EM, expectation-maximisation) **and** (algorithm, clustering, method), (hierarchical, DBSCAN, gaussian, density-based) **and** clustering, mean shift, gaussian mixture model, clustering **and** (algorithm, analysis, method)
- (decision, CART, classification and regression) **and** tree, iterative dichotomiser 3, ID3, random forest, C4.5, chi squared automatic interaction detection, CHAID, ensemble **and** (learning, method, algorithm), adaboost, (adaptive, gradient) **and** boosting, xgboost, bootstrap aggregation, stacked generalisation
- expert system, genetic algorithm, computational intelligence, rule-based learning, (bio-inspired, biologically-inspired, neuro-inspired, neural-inspired, nature-inspired) **and** (learning, computing, algorithm, network, intelligence, architecture, clustering), swarm intelligence, (ant, bee, fish, locust, whale) **and** (algorithm, intelligence)
- (reinforcement, temporal difference) **and** learning, deep Q-network, DQN, Q-learning, Q-table, state–action–reward–state–action, SARSA, TD learning, (positive, negative) **and** reinforcement, actor-critic, A3C, TRPO, PPO, DDPG TD3, QR-DQN, I2A, MBMF, MBVE, epsilon-greedy, multi-armed bandit, trust region-guided proximal policy optimisation, deep deterministic policy gradient, model-based value expansion, chauffeurnet

- (federated, alliance) **and** (learning, model, AI, horizontal, vertical, longitudinal, averaging, aggregation), blockFL, FedSGD
- transfer learning, TLlib
- (zero-order, zero-shot, zero-sample, data-less, one-order, one-shot, few-shots, few-orders) **and** (learning, inference)
- natural language, speech-to-text, text-to-speech, text-to-phoneme, (speech, voice) **and** (analysis, recognition, synthesis), text **and** (classification, analysis), sentiment analysis, word2vec, word segmentation, fastText, sentence encoder, textual entailment, entity typing, large language model, BERT, XLNet, multi-lingual, bi-lingual, machine translation
- computer vision, (vision, visual) **and** processing, object detection, image **and** (classification, recognition), scene **and** (reconstruction, restore, transform, parse, recreate, understand), (facial, iris, target) **and** (detect, recognition, authenticate, verify), SLAM algorithm, locality mapping, VGG, Xception, ResNet, ImageNet
- XAI, XNN, XGNN, explainable, interpretable, SHAP, shapley additive explanations, LIME, local interpretable model-agnostic explanations, partial dependence plot, layer-wise relevance propagation, contrastive explanation, concept activation vector
- accelerator, chip, chipset, system-on-chip, processor, hardware, neuromorphic, FPGA, CPU, GPU, TPU, tensor processing unit, neural processing unit, vision processing unit

Main IPC/CPC used

- G06N3/02, G06N3/0475, G06N3/0464, G06N3/092, G06N3/096, G06N3/098, G06N5/045, G06K9/003, G06F18/23, G06F18/27, G06N20/20, G10L, G11C11/54, G06K2209

Industries

Main keywords used

- classroom, teaching, student, pupil, teacher, school, education, lesson, assignment, exam, test, question, homework
- healthcare, health, medical, medicine, clinical, hospital, doctor, patient, surgery, surgical, disease, Parkinson, Alzheimer, blood pressure, hypertension, diabetes, cardiovascular, sleep apnea, dengue, malaria, coronary disease, cancer, ophthalmic, arrhythmia, epilepsy, stroke, illness, computed tomography, magnetic resonance imaging, X-ray
- finance, fintech, credit, investment, insurance, banking, portfolio, stock, fraud, mortgage, payment, debt, loan, asset, underwriting, arrear, remittance, currency, bond, insurance, investment transaction
- cybersecurity, cyberattack, cyberthreat, malware, malicious, virus, DDOS, denial of service, APT, advanced persistent threat, ransomware, honeypot, hacker, spyware, phishing, spoofing, botnet, man-in-the-middle, trojan,

disinformation, misinformation, intrusion, penetration testing, network security, zero-day, social engineering, access control, data security
- order fulfilment, goods **and** (pick, sort, inventory), coldchain, freight, logistics, last mile, supply chain, warehouse
- manufacturing, assembly line, production line, factory, industrial **and** (robot, automation, equipment), fault, abnormality, defect, anomaly, failure
- (luggage, person, cargo) **and** (security, inspection, surveillance), smuggling, contraband, illegal, terrorism, prohibitive, travel document, passport, immigration, airport, customs, security checkpoint, customs border
- (urban, city, town, estate, municipal) **and** (plan, manage), (crowd, traffic, pollution, emission, waste, public utilities) **and** (control, monitor, predict, maintain, repair)
- government, civil, citizen, (community, public) **and** (engage, complain, satisfaction, feedback, consult, interact, service, opinion, emotion)

Main IPC/CPC used

- G06Q50/20, G16H, G06T7/0012, A61B5, G06Q40/02, G06Q40/03, G06Q40/04, G06Q40/06, G06Q40/08, G06Q20, H04L63, G06Q50/28, G06Q10/08, G05B19/41875, G05B19/41865, G06Q50/26

Annex C: Additional Information

Exhibit C-1: Top 10 AI innovators in each country

China	U.S.	South Korea
Baidu [9,543]	IBM [7,234]	Samsung Electronics [5,011]
Tencent Holdings [7,253]	Microsoft [3,293]	LG Electronics [2,112]
State Grid Corp [6,463]	Google [3,150]	Elect Telecom Research Inst[1,695]
Ping An Tech [5,712]	Amazon Tech [1,857]	Korea Adv Inst Sci Tech [929]
Zhejiang Uni [4,502]	Intel [1,644]	Seoul National Uni [773]
Uni Elect Sci Tech China [4,027]	Qualcomm [1,271]	Hyundai Motor [666]
Xidian Uni [3,678]	Adobe Systems [1,071]	Yosei Uni [662]
Huawei [3,643]	Apple [947]	Korea Uni [571]
Tsinghua Uni [3,565]	Meta Platforms [886]	Hanyang Uni [409]
Alibaba [3,465]	Capital One [865]	KT Corp [357]

Germany	U.K.	Canada
Robert Bosch [1,498]	DeepMind [282]	BlackBerry [133]
Siemens Healthineers [880]	Cirrus Logic [158]	Royal Bank of Canada [117]
Siemens AG [736]	BT [155]	Toronto Dominion Bank [100]
SAP SE [521]	Arm Holdings [154]	Huawei Canada [96]
Fraunhofer [479]	Oxford University [76]	Element AI [90]
Bayerische Motoren Werke [337]	Imagination Technologies [75]	Malikie Innovations [50]
Volkswagen AG [287]	Jaguar Land Rover [58]	University of Toronto [46]
Daimler AG [283]	Imperial College [34]	ServiceNow Canada [31]
Mercedes-Benz Group [280]	Graphcore [32]	OpenText [29]
Continental AG [245]	BAE Systems [26]	Distech Controls [28]

Netherlands	Israel	Singapore
Philips [1,168]	NICE [73]	Lenovo (Singapore) [222]
HERE Global [182]	Biosense Webster (Israel) [59]	BIGO Technology [190]
Dolby International AB [146]	Mazor Robotics [52]	Alibaba Singapore [118]
ASML [114]	Technion – Israel Inst Tech [51]	SenseTime [74]
NXP [92]	OrCam Technologies [45]	A*STAR [73]
Signify [46]	Mobileye [44]	NTU [67]
TNO [14]	Given Imaging [41]	NUS [66]
Kepler Vision Technologies [13]	Ramot at Tel Aviv University [36]	Sivantos [44]
NavInfo Europe [9]	BGN Technologies [35]	Alipay Labs Singapore [37]
Promaton [8]	Verint Systems [34]	Smith+Nephew [29]

Sweden	Finland	Denmark
Ericsson [652]	Nokia [722]	Oticon [58]
Spotify [78]	WithSecure [12]	GN Hearing [30]
Volvo Cars [57]	Kone [11]	Siemens Gamesa [18]
Axis [48]	Elisa [10]	GN Audio [15]
Fingerprint Cards [27]	Curious AI [7]	Unity Ipr ApS [12]
Veoneer [27]	Supercell [7]	Widex [10]
Assa Abloy [25]	Suunto [7]	Moodagent [8]
Arriver Software [23]	IPRally Technologies [6]	University of Copenhagen [8]
Scania [22]	APLcomp [5]	3Shape [7]
Elekta [17]	Oura Health [5]	Danmarks Tekniske Universitet [5]

Exhibit C-2: NVIDIA's AI patenting trend

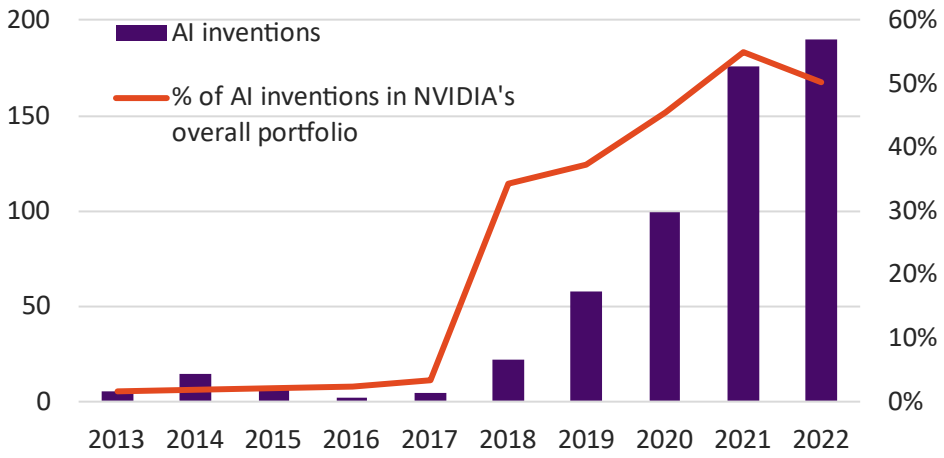


Exhibit C-3: Top innovators in LSTM and Transformer

	Top players in LSTM	Top players in Transformer
China	State Grid Corporation [399] Uni Elect Sci Tech China [145] Chongqing Uni Posts and Telecom [120] Zhejiang Uni [119] Ping An Technology [116]	Ping An Technology [98] Chongqing Uni Posts and Telecom [35] Kunming Uni Sci Tech [32] Uni Elect Sci Tech China [29] Hangzhou Dianzi Uni [27]
Rest of the world	Google [30] IBM [18] Tata [18] Microsoft [14] Adobe Systems [12]	Microsoft [22] Salesforce [10] Google [5] IBM [3] Adobe Systems [3]

Exhibit C-4: Breakdown of transfer and N-shot learning inventions by uses

Uses of transfer learning and N-shot learning in natural language processing and computer vision register higher growth from 2017-2022 compared to other uses.

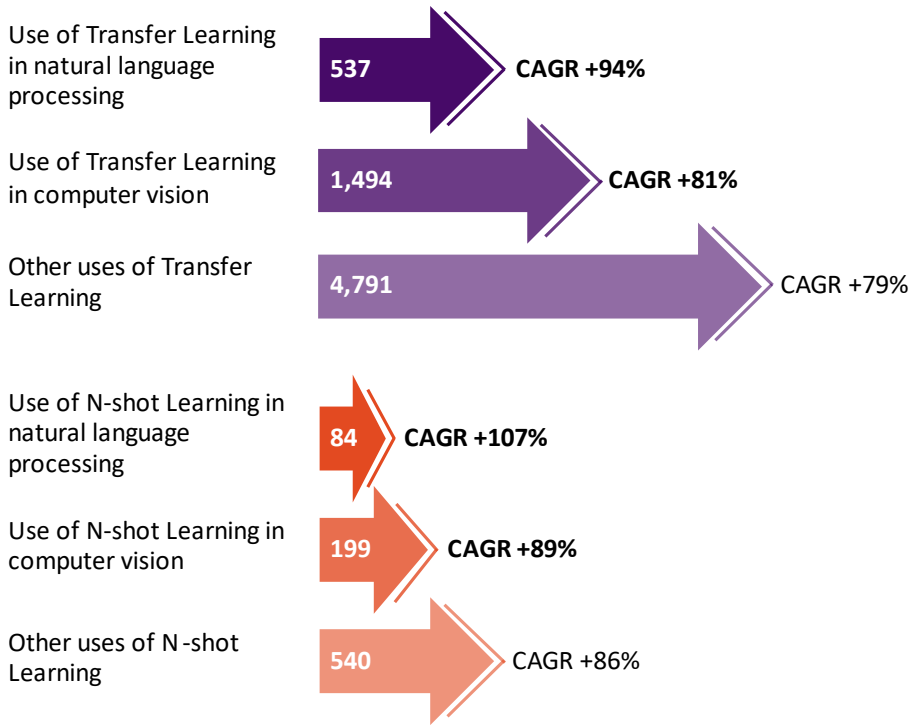
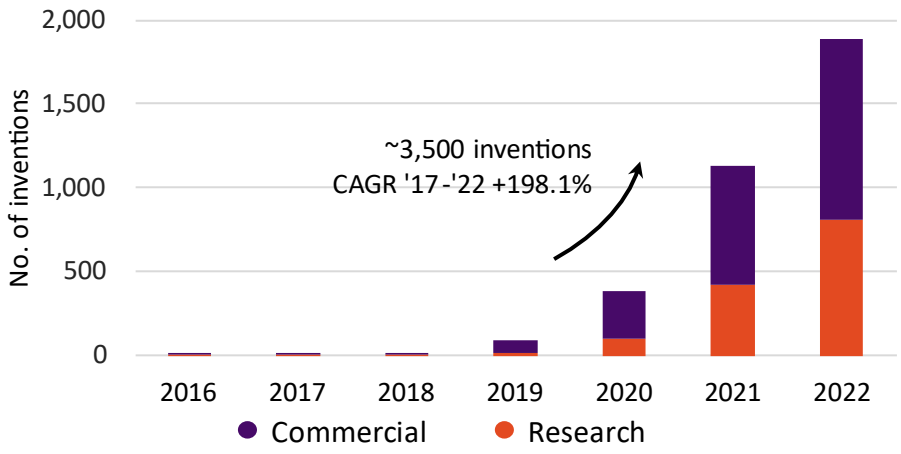
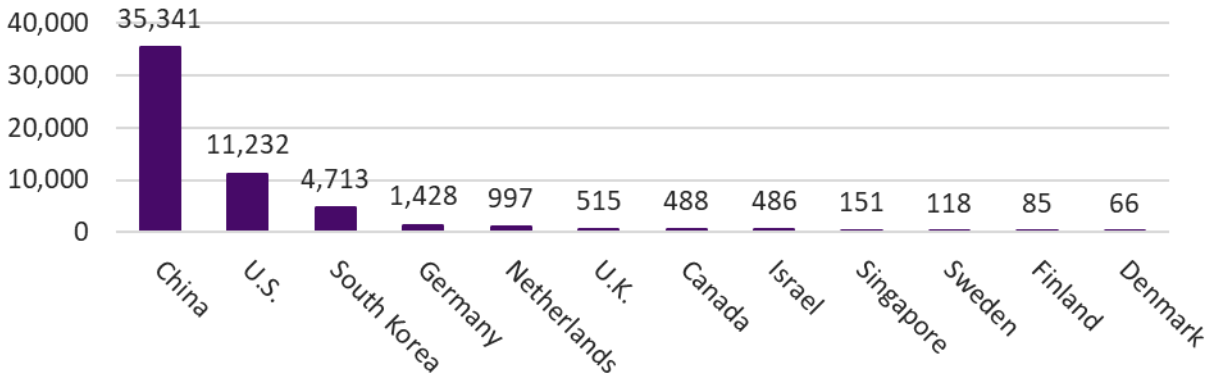


Exhibit C-5: Patenting trend of federated learning (top) and top innovators (bottom)



China	U.S.
WeBank [319]	IBM [38]
Ping An Technology [84]	Qualcomm [38]
Alipay Information Technology [83]	Google [21]
Beijing Uni Posts Telecom [79]	**South Korea**
Clustar 深圳致星科技 [71]	LG Electronics [29]
Baidu [62]	Samsung Electronics [15]
Huawei [54]	Korea Adv Inst Sci Tech [5]
Xidian Uni [47]	

Exhibit C-6: Country rankings (based on no. of inventions) and top innovators in healthcare

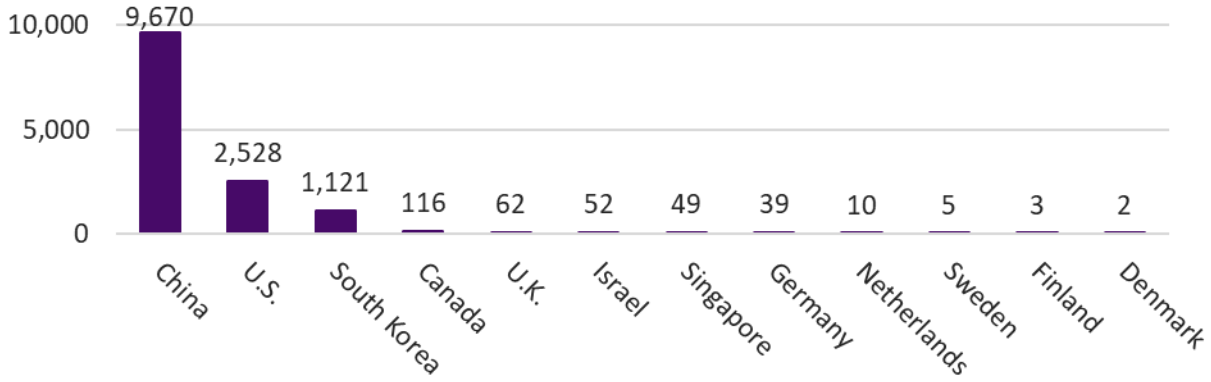


China	U.S.	South Korea	Germany
Ping An Tech [798]	IBM [620]	Samsung Electronics [254]	Siemens Healthineers [882]
United Imaging Healthcare [695]	Merative [241]	Yonsei Uni [174]	Carl Zeiss [62]
Zhejiang Uni [505]	Uni of California [209]	Korea Uni [150]	Roche [45]
Fudan Uni [463]	GE Precision Healthcare [208]	Korea Adv Inst of Sci & Tech [104]	Bayer [32]
Sichuan Uni [453]	General Electric [194]	ASAN Foundation [93]	Robert Bosch [31]

Netherlands	U.K.	Canada	Israel
Philips [928]	Oxford Uni [49]	Uni Health Network [18]	Biosense Webster [53]
Pie Medical Imaging [8]	Micromass [14]	Analytics 4 Life [18]	Mazor Robotics [52]
Promaton [6]	Uni College London [14]	Synaptive Medical [11]	OrCam Tech [45]
Agendia [5]	Optos [12]	NuraLogix [10]	Given Imaging [41]
InnoSIGN [4]	BenevolentAI [11]	McGill Uni [10]	Intuition Robotics [26]

Singapore	Sweden	Finland	Denmark
Sivantos [44]	Elekta [17]	Nokia [28]	Oticon [58]
A*STAR [33]	RaySearch Lab [11]	Oura Health [5]	3Shape [7]
Smith+Nephew [29]	Exini Diagnostics [8]	Suunto [4]	Novo Nordisk [5]
NUS [17]	Acorai [5]	Aiforia [3]	Uni of Copenhagen [8]
Singapore Health Services [16]	AstraZeneca [5]	Avaintec [3]	Coloplast [4]

Exhibit C-7: Country rankings (based on no. of inventions) and top innovators in finance



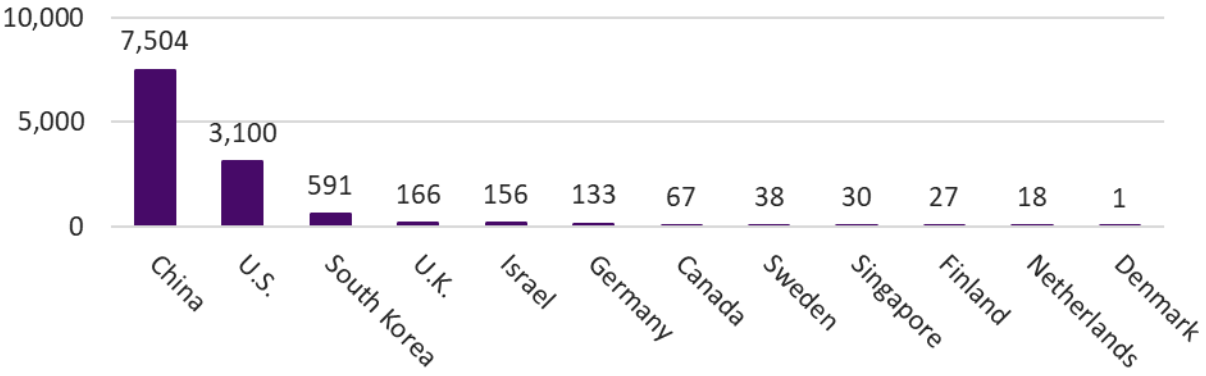
China	U.S.	South Korea	Canada
Bank of China [1,036]	Capital One [228]	Bizmodeline [68]	Toronto Dominion Bank [35]
Ind Commercial Bank China [930]	Mastercard [108]	Samsung Electronics [26]	Royal Bank of Canada [13]
Ping An Tech [334]	Visa [92]	Qraft Tech [19]	Wells Fargo Bank [7]
China Construction Bank [229]	IBM [92]	AIZEN Global [17]	Mastercard Canada [5]
WeBank [205]	Bank of America [84]	Team Blackbird [9]	Shopify [3]

U.K.	Israel	Singapore	Germany
Featurespace [3]	Actimize [7]	Alipay Labs Singapore [26]	SAP [16]
Refinitiv [3]	VATBox [7]	Mastercard Asia Pac [11]	
Tractable [2]	NICE [2]	OneConnect [6]	
	HUB Security [2]	Amaris AI [2]	
	BioCatch [2]	TSLC [2]	

Netherlands	Sweden	Finland	Denmark
NXP [2]	Ericsson [2]		

Note: Only players with 2 or more inventions are listed.

Exhibit C-8: Country rankings (based on no. of inventions) and top innovators in cybersecurity



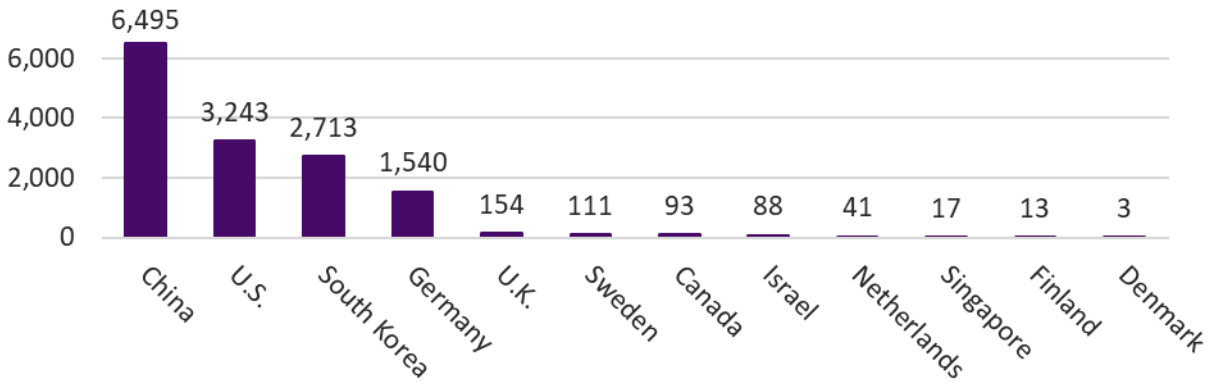
China	U.S.	South Korea	U.K.
State Grid Corp [272]	IBM [231]	Samsung Electronics [29]	BT [57]
Tencent [118]	Microsoft [178]	Elect Telecom Research Inst [28]	Sophos [25]
Inst of Information Eng [118]	Cisco [120]	Korea Uni [16]	Darktrace [17]
Beijing Uni of Posts Telecom [106]	Bank of America [107]	IGLOO Security [13]	Cirrus Logic [10]
Zhejiang Uni of Tech [101]	Intel [75]	Agency for Defense Dev [13]	Mimecast Services [2]

Israel	Germany	Canada	Sweden
BGN Tech [16]	Robert Bosch [32]	Royal Bank of Canada [10]	Ericsson [26]
Cognyte Software [16]	Siemens AG [31]	BlackBerry [8]	Fingerprint Cards [3]
CyberArk Software [14]	SAP [20]	Toronto Dominion Bank [6]	Assa Abloy [3]
Twistlock [6]	Deutsche Telekom [14]	Mastercard Canada [5]	Debricked [2]
Armis Security [6]	NEC Lab Europe [10]	Interset Software [2]	

Singapore	Finland	Netherlands	Denmark
Certis Cisco [4]	WithSecure [12]	NXP [9]	
Flexxon [4]	Nokia [11]	Elasticsearch [2]	
Singapore Uni Tech Design [4]	Elisa [2]		
Ensign InfoSecurity [4]			
Singapore Management Uni [3]			

Note: Only players with 2 or more inventions are listed.

Exhibit C-9: Country rankings (based on no. of inventions) and top innovators in transport



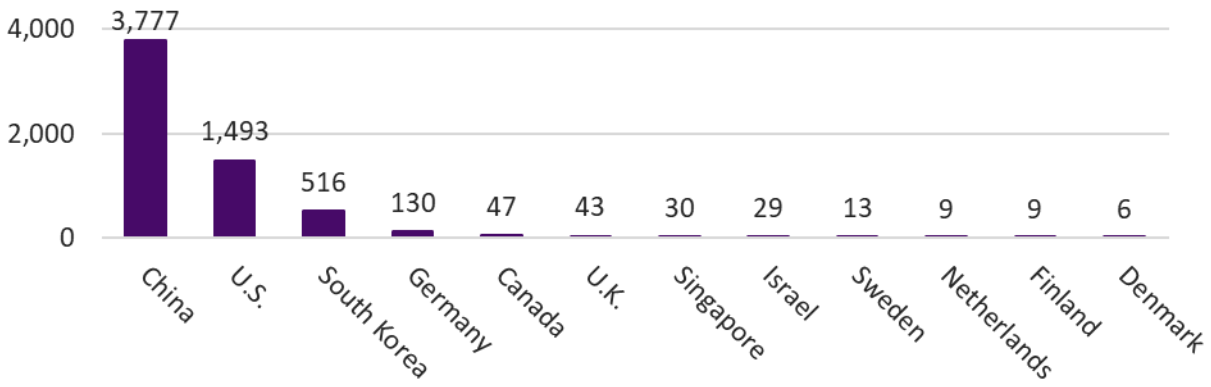
China	U.S.	South Korea	Germany
Apollo [201]	Ford [400]	LG Electronics [375]	Robert Bosch [324]
Baidu [144]	General Motors [265]	Hyundai Motor [355]	BMW [185]
Jilin Uni [130]	Toyota Motor North America [143]	Kia Motors [187]	Volkswagen AG [160]
Huawei [87]	Boeing [96]	Hyundai Mobis [157]	Daimler AG [148]
Nanjing Uni Aeronautics Astronautics [83]	Waymo [79]	Samsung Electronics [70]	Audi AG [122]

U.K.	Sweden	Canada	Israel
Jaguar Land Rover [30]	Volvo Cars [37]	Magna [11]	Mobileye [44]
Airbus Operations [6]	Scania [13]	Huawei Canada [9]	Autobrains [14]
GE Aviation Systems [6]	Zenuity [11]	BlackBerry [9]	Upstream Security [5]
ZF Automotive UK [4]	Arriver Software [9]	Ground Transportation Syst [8]	VayaVision Sensing [3]
Thales UK [4]	Volvo Trucks [9]	ServiceNow Canada [4]	Argus Cyber Security [2]

Netherlands	Singapore	Finland	Denmark
HERE Global [16]	NTU [6]	Wärtsilä [4]	
NXP [7]	NUS [2]		
Orlaco Products [4]	Lenovo [2]		
Prodrive Tech [3]			
MobileDrive [2]			

Note: Only players with 2 or more inventions are listed.

Exhibit C-10: Country rankings (based on no. of inventions) and top innovators in logistics



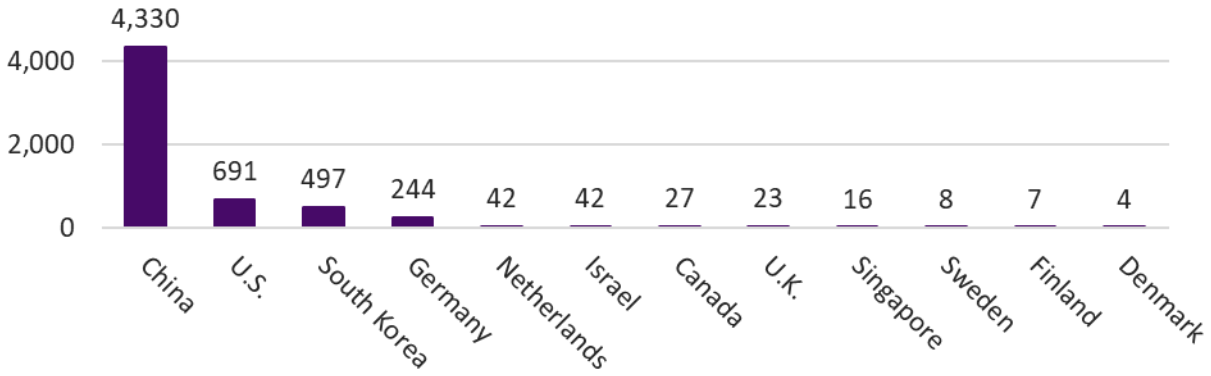
China	U.S.	South Korea	Germany
Jingdong [188]	Walmart [132]	Coupang [56]	Siemens AG [13]
Cainiao [119]	IBM [96]	Colosseum [21]	Robert Bosch [11]
SF Tech [118]	Amazon Tech [94]	LG Electronics [16]	SAP [10]
Shanghai Dongpu Software [117]	Capital One [23]	Cafe24 [9]	Deutsche Post [8]
Beijing Sankuai Online Tech [58]	Maplebear (Instacart) [23]	Samsung Electronics [6]	Daimler AG [7]

Canada	U.K.	Singapore	Israel
Shopify [8]	Ocado [5]	Trax Tech [9]	TrueNorth [2]
6 River Systems [4]	EVRYTHNG [3]		
Canscan [2]	Sony Europe [3]		
Kinaxis [2]			

Sweden	Netherlands	Finland	Denmark
	HERE Global [2]	ConexBird [2]	Maersk [3]
		Nokia [2]	Portchain [2]

Note: Only players with 2 or more inventions are listed.

Exhibit C-11: Country rankings (based on no. of inventions) and top innovators in manufacturing



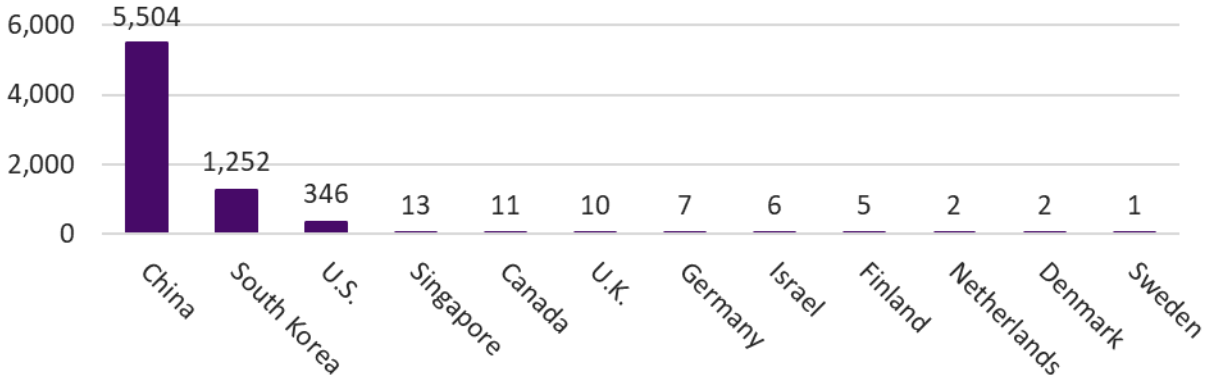
China	U.S.	South Korea	Germany
Zhejiang Uni [63]	Rockwell Automation [42]	Samsung Electronics [34]	Siemens AG [94]
South China Uni of Tech [57]	KLA [41]	Korea Inst of Ind Tech [15]	Robert Bosch [26]
Huazhong Uni of Sci and Tech [57]	IBM [32]	Samsung Display [15]	BASF [10]
Guangdong Uni of Tech [51]	Applied Materials [29]	Wizcore [10]	TRUMPF [9]
Tongji Uni [44]	General Electric [22]	LG Electronics [9]	SMS Group [6]

Netherlands	Israel	Canada	U.K.
ASML [33]	Applied Materials Israel [12]	ATS Corp [5]	Cheyney Design & Dev [2]
	Siemens Ind Software [7]	Honeywell [2]	Flexciton [2]
	Kitov Systems [2]	Timber Tech [2]	Oden Tech [2]
	Inspekto AMV [2]		
	Nova [2]		

Singapore	Sweden	Finland	Denmark
Emage AI [3]	Unibap [2]	Elisa [2]	
NUS [3]			
Global-Foundries [2]			
Smith+Nephew [2]			

Note: Only players with 2 or more inventions are listed.

Exhibit C-12: Country rankings (based on no. of inventions) and top innovators in education



China	South Korea	U.S.	Singapore
Central China Normal Uni [130] Squirrel AI [129] Guangdong Xiaotiancai Tech [128] Ping An Tech [65] VIPKID [40]	Riiid [61] i-Scream Edu [17] Ewha Womans Uni [17] OneSecondLabs Inc [12] Woongjin ThinkBig [8]	IBM [28] Pearson [26] Microsoft [21] Kadenze [4] Oracle [4]	Education in Motion [3]

Canada	U.K.	Germany	Israel
	OBRIZUM Group [4]	EDUCATION4 SIGHT [2] Siemens AG [2]	

Finland	Netherlands	Denmark	Sweden

Note: Only players with 2 or more inventions are listed.

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