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WHICH COMPANIES ARE AHEAD IN FRONTIER INNOVATION ON CRITICAL TECHNOLOGIES? COMPARING CHINA, THE EUROPEAN UNION AND THE UNITED STATES

ALICIA GARCÍA-HERRERO, MICHAL KRYSTYANCZUK AND ROBIN SCHINDOWSKI

Competition in critical technologies is attracting increasing attention not only because of the foundational nature of these technologies for other types of innovation, but also because of their role in the United States national security strategy. In this paper, we look into which entities in China, the European Union and the US innovate at the technology frontier in the three most important critical technologies – artificial intelligence, quantum computing and semiconductors – based on identification of the most radical novel patents in these technologies and their subsectors. Working with these pathbreaking patents, we look into the origin of the companies that file the largest numbers of them. US innovators dominate the innovation frontier for quantum computing and, to a lesser extent, AI, with Chinese innovators doing better in semiconductors. European innovators lag in all, but perform relatively better in quantum computing, in which they rank similarly to Chinese innovators. Furthermore, the innovation ecosystem is quite different across geographies. In the US, tech companies top the rankings of critical novelties and are highly concentrated: as many as three companies are in the top rankings of all of the three critical technologies. Frontier innovators in the field in which the EU competes most equally – quantum – are mostly research centres and not companies. China lies somewhat in between in all three domains.

JEL: O30, O33, F52
Key words: critical technologies, patents, innovation, AI, quantum computer, semiconductors

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1 Introduction

Quantum computing, semiconductors and artificial intelligence are at the centre of the United States-China technology rivalry. They are foundational technologies with large spillover effects and potential gains in productivity, and are therefore essential to the technological autonomy of any major economy. Some have even argued that economic singularity – the point at which machine intelligence is capable of innovating autonomously and beyond human capabilities – will result from progress in these technologies (Nordhaus, 2021). AI is at the core of this. It promises to improve human judgement by providing predictive insights from historical data through simulating human intelligence (Agrawal *et al*, 2018). Furthermore, through techniques of computer vision and game simulation, AI has the potential to grant a significant advantage on the battlefield to those powers that can harness it (Scharre, 2024).

The advancement of AI, however, depends crucially on computing power, for which the deployment and further development of cutting-edge semiconductors are necessary. The semiconductor industry is characterised by a highly globalised supply chain and by high concentration with respect to the production of advanced logic chips needed for AI development. It is therefore particularly subject to geopolitical risk.

Finally, quantum computing is the most embryonic of the three technologies, but the economic implications are potentially huge. Once matured, quantum computing could render traditional semiconductor chips redundant, ending the age of silicon. Hence, it may enable breakthroughs in AI, biotechnology, agricultural technology, material sciences and cybersecurity that would be impossible for traditional supercomputers (Kaku, 2023).

Because of the importance of these three technologies for future competitiveness, China, the European Union and the US – the world's largest economic blocs – are promoting their advancement with growing resources for research and development (R&D) and industrial-policy strategies. The US adopted the CHIPS and Science Act in 2022[1] to further develop a US-based semiconductor ecosystem while attracting foreign investment. In addition, the US federal government has attempted to curtail the transfer to China of high-end semiconductors – and the components to produce them. China has prioritised for much longer the development of these technologies in its national industrial plans. In particular, it set up the National Integrated Circuit Industry Investment Fund in 2014, with a total of $98.38 billion in raised funds as of today. China has also implemented dedicated industrial policy initiatives such as the National Guideline for the Development and Promotion of the Integrated Circuit Industry (2014)[2] and the New Generation Artificial Intelligence Plan (2017)[3]. Finally, less is known about how China supports quantum computing, although it appears as a priority in central five-year plans. The EU, meanwhile, has adopted the European Chips Act (Regulation (EU) 2023/1781) and has started to invest heavily in AI and quantum-computing R&D through its Horizon Europe research funding programme[4]. Further initiatives exist at the national level in the EU.

In this paper, we study who is engaging in frontier innovation in AI, semiconductors and quantum computing in China, the US and the EU. To do this, we exploit a dataset of 'radically novel' patents in the three technologies created by García-Herrero *et al* (2025). The authors use a large language model (LLM) to gauge the degree of

[1] The text of the law is available at https://www.congress.gov/117/plaws/publ167/PLAW-117publ167.pdf.
[2] See (in Chinese) https://www.gov.cn/xinwen/2014-06/24/content_2707281.htm.
[3] See (in Chinese) https://www.gov.cn/zhengce/content/2017-07/20/content_5211996.htm.
[4] Dan Cooper, Lisa Peets, Marty Hansen, Sam Jungyun Choi and Marianna Drake, 'European Commission Announces New Package of AI Measures', *Inside Global Tech*, 14 February 2024, Covington, https://www.insideglobaltech.com/2024/02/14/european-commission-announces-new-package-of-ai-measures/.

novelty of patents and then categorise these novelties into subfields within the three above-mentioned technologies (eg memory technology in semiconductors). This paper is an extension of García-Herrero *et al* (2025). We shed light specifically on: 1) the entities that file the highest number of radical novelties in each technology, and 2) the subfields in which these entities innovate. This more granular analysis allows us to better understand where China, the EU and the US stand in this tech race, as well as relevant differences in their approaches to innovation, whether in terms of the subfields in which research efforts are focused, or the types of entity that conduct the top-level research with visible outcomes, namely radically novel patents in these three fields.

2 What radical novelty in patented technology reveals and what it does not

García-Herrero *et al* (2025) applied an LLM to the universe of patents filed at the main patent registries (the US, the EU and the World Intellectual Property Organization (WIPO), ie the USPTO, EPO and PCT) between 2019 and 2023[5]. Specifically, we define a patent as a 'radical novelty' in a particular field if the related innovation, identified from the patent abstract through the LLM, has never appeared before in a patent grant since 1979, and the innovation appears at least five times in subsequent patents. The subfields reviewed for each critical technology in the next few sections are also identified by classifying all available patents through an LLM. While García-Herrero *et al* (2025) focused on the general subfield evolution within each region and related cross-regional patterns, in this paper, we focus on the entities that file the highest numbers of radical novelties for each region and for each technology.

First, however, we want to offer a few words of caution on the indicator we use. A radical novelty as we have defined it is meant to reveal which entities are patenting technologies that are likely to alter the trajectory of the technology frontier in the future. This has two implications.

First, we look only at patented technology. While patents have been used extensively to quantify the innovative performance of an economy, we acknowledge that, just like every innovation metric, it comes with limitations. Some firms might not disclose their technology in a patent to guard secrecy. A prominent example is Coca Cola, which never filed a patent for its recipe. Some Chinese firms might not disclose their technological progress in order to avoid being sanctioned by the US government.

Second, while we provide statistics on entity-level shares of radical novelties in total patent counts, we want to emphasise that our concept of radical novelty omits incremental innovations that would nevertheless be crucial in the advancement of the industry and a given firm's commercial success. For example, the sum of sustained small-scale improvements in the efficiency of a photolithography machine might have significant commercial implications but may rely on technologically mature methods. Hence, related patents would not count as radically novel in our analysis. Indeed, we find that Chinese chip manufacturer SMIC files a lot of patents, but only a relatively small fraction of these patents appears to be radically novel. Photolithography machine producer ASML does not even appear among the top ten entities with the most radical novelties. What we are extracting with our concept of radical novelties are the patents that are likely to open up a new technology

[5] Because of inflated patent filing in China as a result of subsidy programmes, we have omitted Chinese domestically filed patents. We do not believe this to be an issue as the three technologies of concern are subject to fierce international competition, and hence, innovators are likely to file with patent offices which offer international validity. For a further discussion, see García-Herrero *et al* (2025).

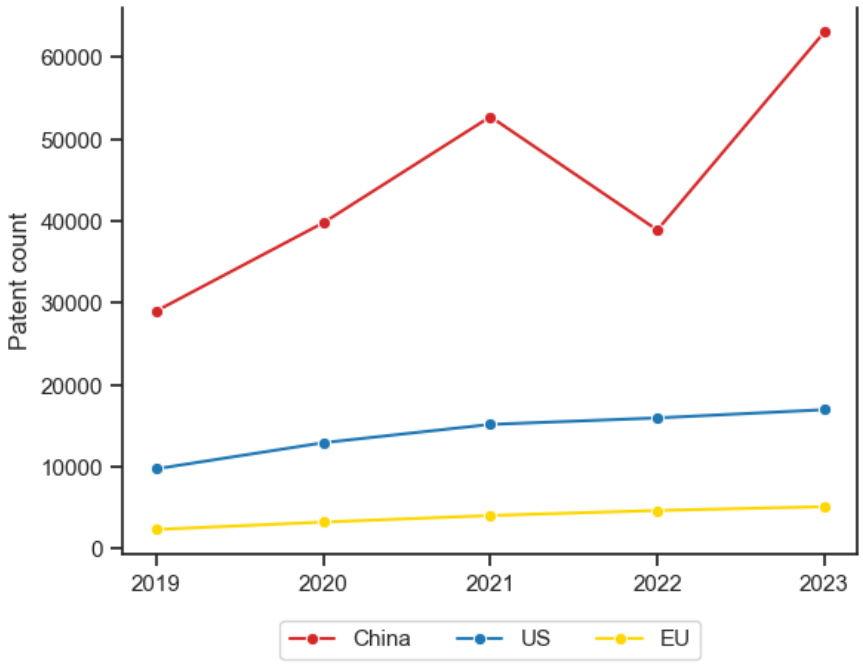
trajectory. These may become commercially valuable in the near or far future and may open up new potential for significant subsequent innovation.

3 Some stylised facts on general patenting trends in critical technologies

Patent filings in AI, quantum computing, and semiconductors help understand the innovation landscape in these critical technologies in China, the EU and the US.

From 2019 to 2023, Chinese AI patents grew remarkably, rising from over 29,000 in 2019 to almost 63,000 in 2023, well above the US number (Figure 1). However, as will become clear later, the seemingly high gap between China and the US in the number of AI patents disappears and actually runs in the US's favour in many AI subfields when the novelty of each patent is taken into account. Entities in the EU tend to file the fewest patents, and our analysis of radical novelties presented later will not change this underwhelming finding.

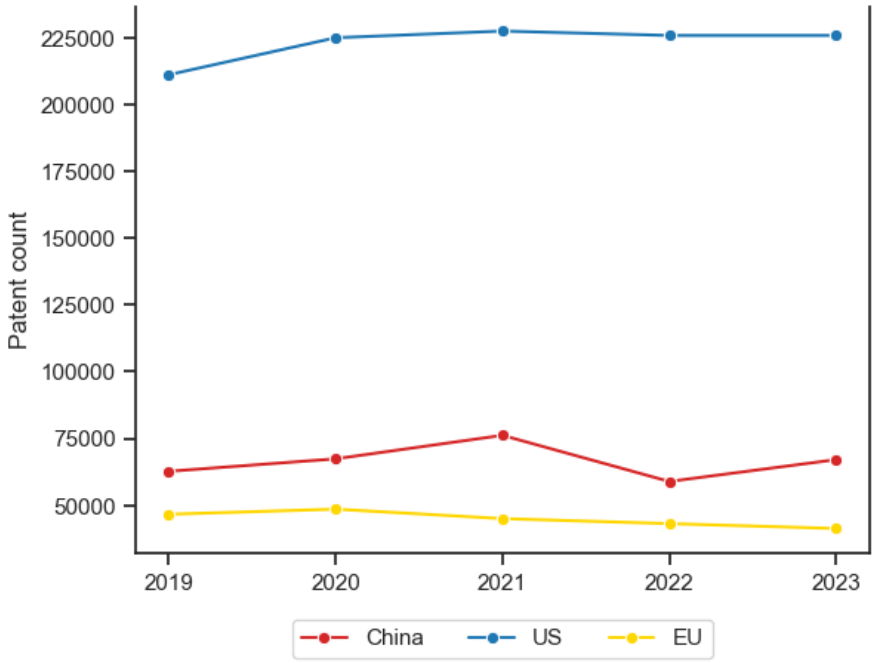
Figure 1: Published patents in semiconductors



Source: WIPO.

The US dominates in terms of numbers of semiconductor-related patents, with more than 210,000 annually (Figure 2). This apparent dominance in patent numbers becomes less evident relative to China when we control for the novelty of the patents. The EU ranks last in the number of chip patents, and the results are quite similar in the analysis to follow when controlling for the novelty of patents.

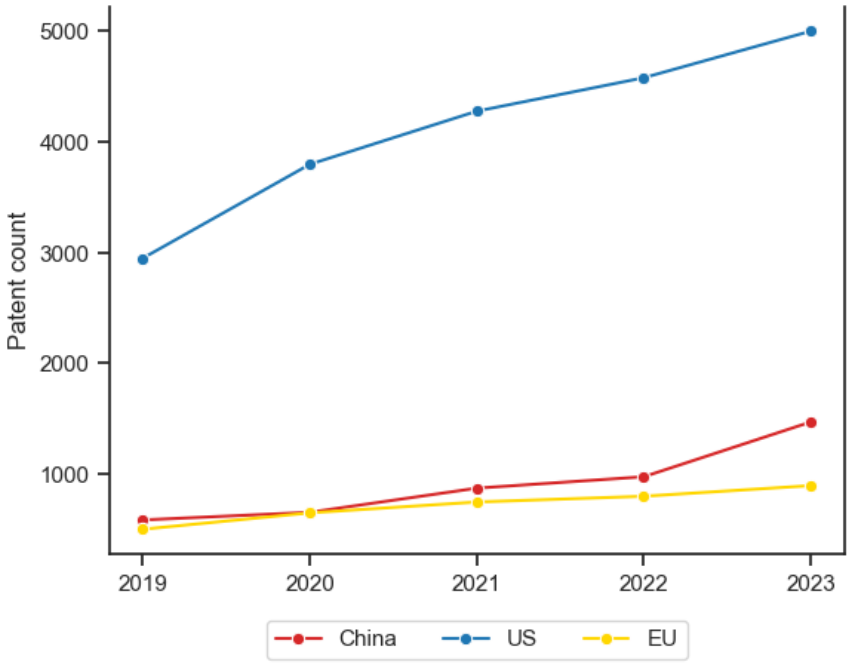
Figure 2: Published patents in artificial intelligence



Source: WIPO.

As for quantum computing, the significantly higher number of patents overall indicates that the US dominates, with China and the EU trailing and with a recent growing gap between China and the EU (Figure 3). Our analysis controlling for the novelty of patents offers a more favourable view of the relative weights of China and the EU, although the US still dominates novel patents in quantum.

Figure 3: Published patents in quantum computing



Source: WIPO.

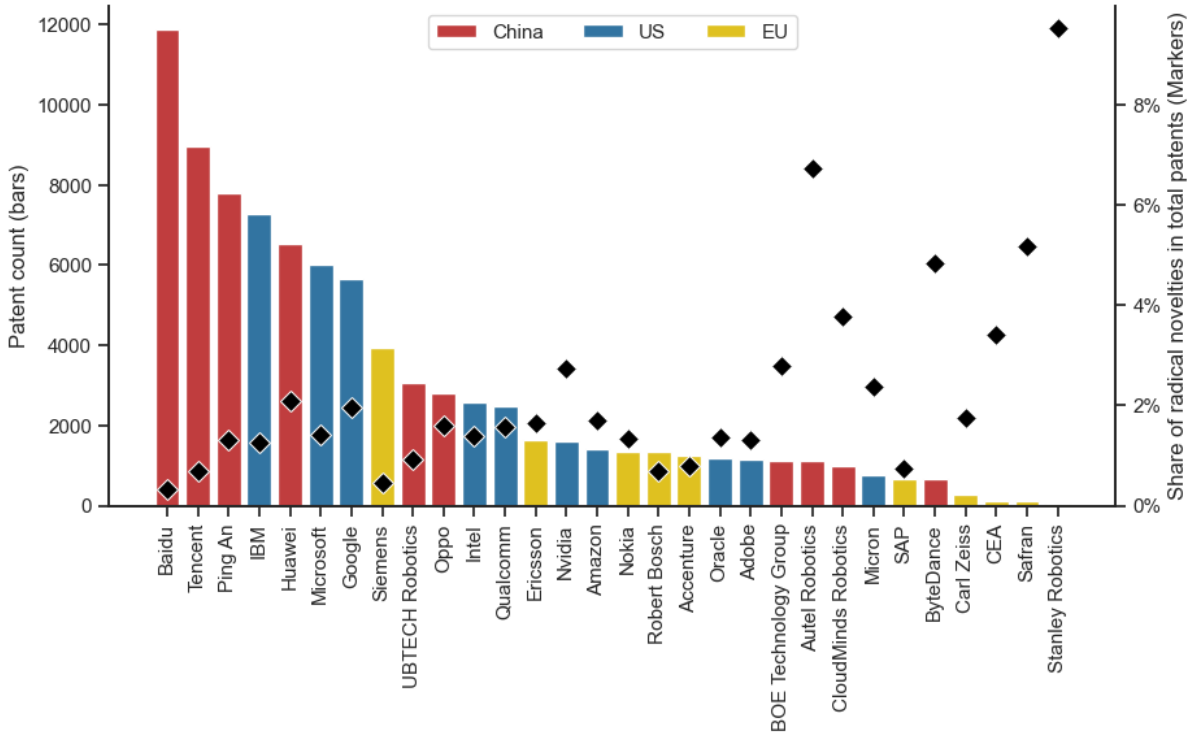
4 How is the patenting landscape evolving in these critical technologies and which companies are most innovative?

To answer this question, we proceed as follows: for each technology and each region, we extract the ten entities (firms, universities or research institutes) with the most radically novel patents published from 2019 to 2023. Throughout the text, we refer to them as 'frontier innovators'. We then use the subfield classification developed in García-Herrero *et al* (2025) to further decompose the radically novel patents of each entity into technology-specific subfields. In what follows, we present the results of this analysis for each of the three technologies.

4.1 Artificial intelligence

Figure 4 shows the ten entities for each region that file the highest number of radically novel patents in AI. A few large technology incumbents from China and the US dominate the raw patent count, represented by the bars. However, the picture looks slightly different when considering the share of patents that count as radical novelty. For most entities this share is between 0.2 percent and 4 percent, with few less actively patenting firms with shares of above 4 percent. French robotics firm Stanley Robotics has the lowest total number patents published between 2019 and 2023 – 63 – but six of these patents were 'radical novelties'. At the other end of the spectrum, Baidu ranks highest among the patent holders with 11,879 total patents, but only 0.33 percent of its patents contain a radically novel innovation. In what follows, we examine China, the US and EU separately, beginning with China.

Figure 4: Patent count and share of radical novelties by entity (AI)



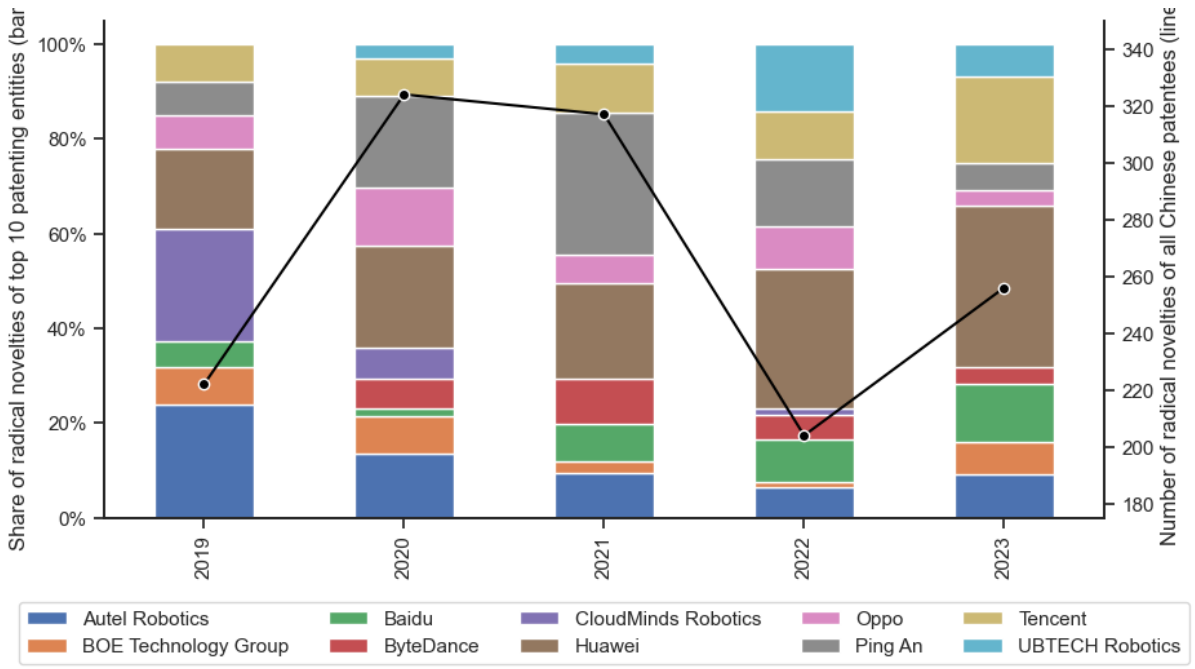
Source: Bruegel based on WIPO.

Figure 5 shows the most prominent Chinese patentees of radical novelties in AI and their shares of these patents among frontier innovators over time. Some well-known large Chinese technology corporations are

among them, including Huawei, insurance firm Ping An, drone manufacturer Autel Robotics, WeChat parent firm Tencent, AI firm Baidu, TikTok parent firm ByteDance and smartphone and IoT device manufacturer Oppo. The most important frontier innovators are Huawei and Ping An. Ping An reached its highest share in 2021 with 29.94 percent of radical novelties, and Huawei did so in 2023 with 34.09 percent. Tencent also increased its share from 7.96 percent in 2019 to 18.18 percent in 2023.

Alongside these, three major Chinese robotics firms are among the frontier innovators. Autel Robotics is one of China's major drone manufacturers, and its products are used for public security, agriculture and industrial purposes. It accounted for 25 percent of frontier innovators' radical novelties in 2019, but its share dropped to 6.38 percent by 2023. In July 2024, it was placed on the US Entity List[6], restricting the firm's access to US goods, software, and technology. UBTECH Robotics, a manufacturer of service robots, has gained ground in the patenting of radical novelties, appearing for the first time in the data in 2020 and reaching a share of 14.1 percent in 2022. Finally, the operator of cloud services for robotics applications, CloudMinds Robotics, was a major innovator in 2019, accounting for 23.89 percent of the novelties among the top ten firms, but mostly disappeared from the data after 2020.

Figure 5: Radical novelties in AI by entity (China, 2019 – 2023)



Source: Bruegel based on WIPO.

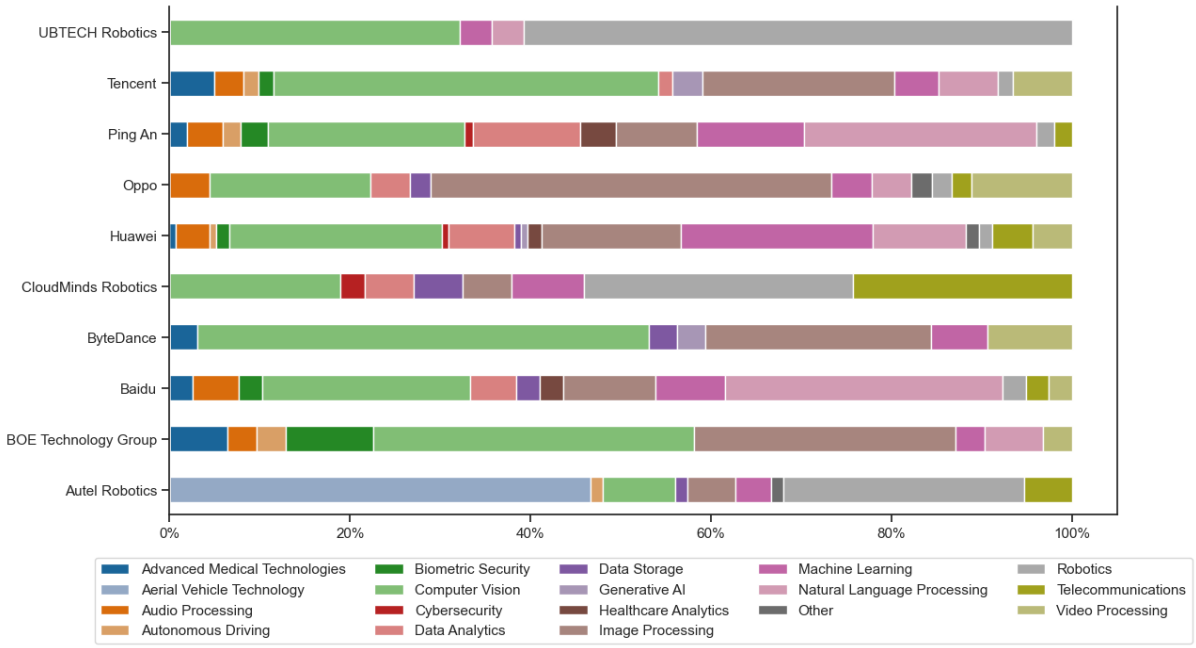
A more detailed picture emerges when looking at the subfields in which the frontier innovators are active. With the exception of Autel Robotics, almost all of the top ten AI innovators from China have made significant contributions in either 'computer vision' or 'image processing'. Chief among these is ByteDance with 75 percent of its radical novelties in the two fields combined, followed by electronics display producer BOE Technology (64.51 percent), gaming and social media giant Tencent (63.93 percent) and Oppo (62.22 percent).

[6] See https://www.bis.gov/entity-list.

In addition to firms that focus on the processing of visual data, robotics firms are drivers of AI innovation in China, although each of the three robotics firms in our subset specialises in somewhat different subfields. UBTECH Robotics' radically novel patents are focused on both 'computer vision' (32.14 percent) and 'robotics' (60.71 percent). Autel Robotics is the only firm in our data innovating significantly in 'aerial vehicle technology' (46.67 percent of its radical novelties). CloudMinds Robotics, as an operator of robotics-related IT infrastructure, is more diversified, appearing also in 'telecommunications' (24.32 percent), 'computer vision' (18.92 percent), 'machine learning' (8.11 percent), 'data storage' (5.41 percent) and 'data analytics' (5.41 percent).

Among the more diversified firms are Huawei and Ping An, which are also the most dominant frontier innovators in this area. Huawei appears to be strong both in the processing of visual and textual data, with shares of 23.53 percent in 'computer vision', 15.44 percent in 'image processing', 21.32 percent in 'machine learning', 10.24 percent in 'natural language processing' (NLP) and smaller but still significant shares in 'data analytics' (7.35 percent) and 'telecommunications' (4.41 percent). Ping An, with heavy investment in healthcare and telemedicine solutions, financial services and fraud detection, has a strong presence in 'natural language processing' (25.74 percent), 'data analytics' (11.88 percent) and 'machine learning' (11.88 percent). Finally, Baidu – as China's largest search engine provider and a major innovator in autonomous driving – has filed a number of novel patents, split into the processing of visual data (33.34 percent in 'computer vision' and 'image processing') and the processing of textual and audio data (30.77 percent in 'natural language processing').

Figure 6: Chinese frontier innovators and their related subfields (AI)

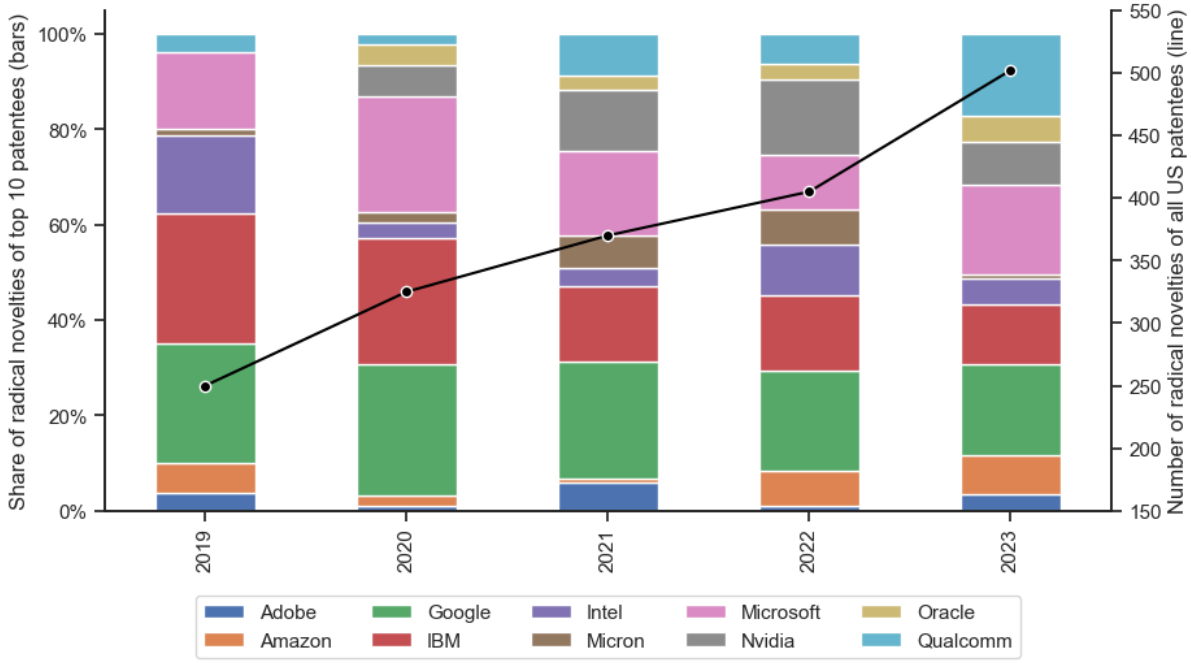


Source: Bruegel based on WIPO.

For the United States, Figure 7 shows the general trend in AI innovation. As can be seen from the line graph with the scale on the right-hand axis, despite the COVID-19 pandemic, and contrary to the trend in China, patenting of radical novelties in AI has strongly accelerated in the US. The number of radical novelties among all innovators in the field (not only those in our subset of frontier innovators) almost doubled from 298 in 2019 to 571 in 2023. Another striking feature is that the US frontier innovators are exclusively large incumbent technology firms, most notably Google, which accounted for a share of 23.86 percent in 2023, Microsoft (18.75 percent) and IBM

(11.93 percent). Qualcomm significantly increased its share from 3.15 percent in 2019 to 20.45 percent in 2023. Chip firms Nvidia and Intel also accounted for strong shares in AI-related frontier innovation in 2023, reaching 6.82 percent and 7.95 percent, respectively. Except for Qualcomm and IBM, the shares of innovation of US AI innovators have remained fairly stable.

Figure 7: Radical novelties in AI by entity (US, 2019 – 2023)



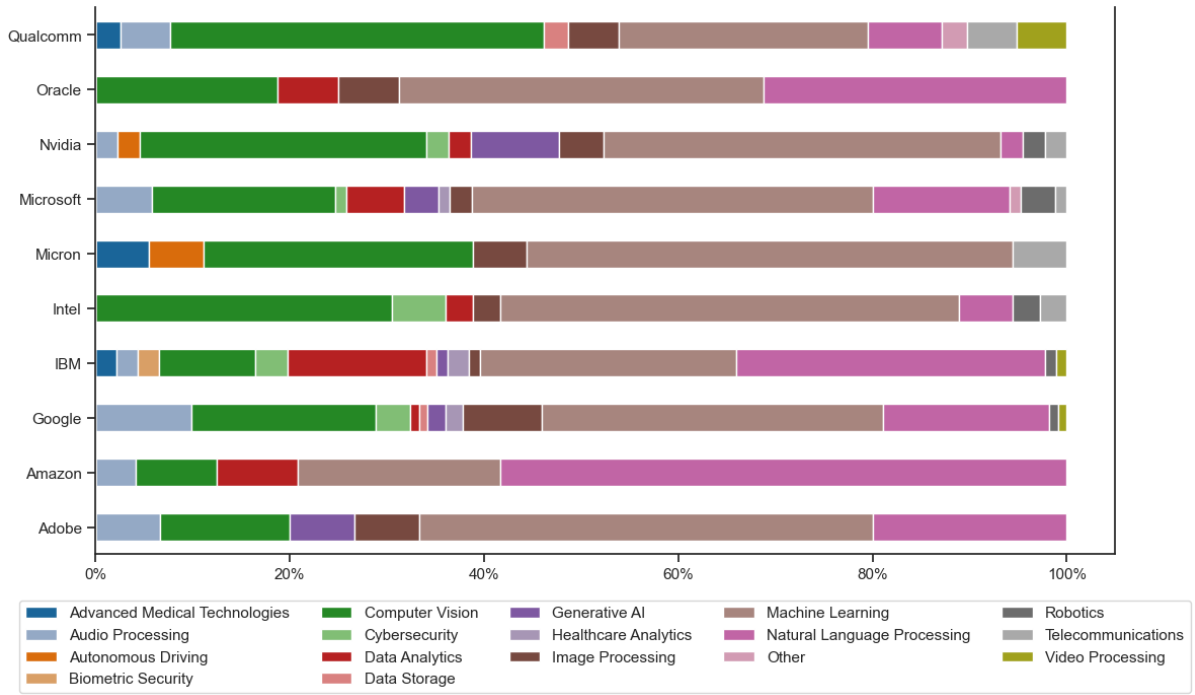
Source: Bruegel based on WIPO.

The categorisation of this innovation into subfields is also telling (Figure 8). First, all frontier innovators hold significant shares of 'machine learning', with Micron holding the largest share, with precisely 50 percent of its radical novelties. Except for Amazon and IBM, companies' shares of 'computer vision' are also substantial, and applications across the frontier innovators are broad. For example, Qualcomm, Nvidia and Micron, for which 38.46 percent, 29.56 percent and 27.78 percent respectively of their radical novelties are in this field, are known to apply computer-vision techniques to autonomous driving, while Google (18.92 percent), IBM (9.89 percent), Intel (30.56 percent) and Nvidia equally use computer vision to enhance their firms' services for the processing of medical images.

'Natural language processing' (NLP) is likewise a strong field, especially for Amazon, which has a share of 58.34 percent of its radical novelties in related innovation, and to a lesser extent Oracle (31.25 percent) and IBM (31.87 percent). This is not surprising, as methods of NLP are offered as a business service by all of these firms. For instance, Amazon Web Services offers NLP techniques to businesses to analyse social-media content and customer feedback. Amazon also relies on NLP for its core business. In its e-commerce segment, NLP contributes to predicting customer types from search queries and optimising product recommendations (Amazon, 2023). IBM and Oracle specialise in the application of NLP for business communications, such as entity recognition, automatic updating of customer information and facilitated search queries for business databases. Amazon and IBM are also innovative in 'data analytics' more generally.

Finally, Nvidia and Adobe are the only firms with a non-trivial share (9.09 percent and 6.67 percent of their radical novelties, respectively) in 'generative AI'. Nvidia's provision of its generative AI platform as a service for the development of OpenAI's ChatGPT is in alignment with this. Given current market trends in the US, we expect this field to grow in importance when it comes to radical innovation.

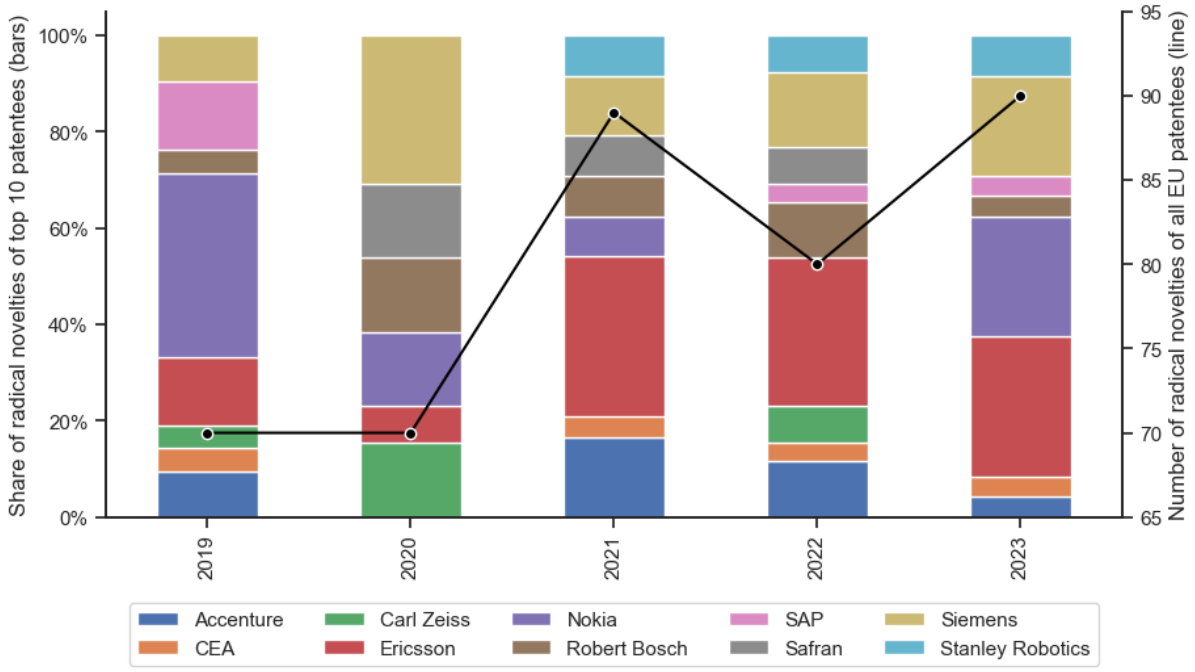
Figure 8: US frontier innovators and their related subfields (AI)



Source: Bruegel based on WIPO.

In the EU, as can be seen from the line graph in Figure 9, the absolute number of radical novelties by EU patentees remains modest compared to the US and China. However, it still grew from 70 in 2019 to 90 in 2023. Major frontier innovators are the two prominent telecommunication firms Ericsson and Nokia, with the former having overtaken the latter in recent years. Siemens has also maintained a substantial share among the top innovators, even though decreasing from 30.77 percent of the total to 20.83 percent in 2023. Since 2021, the French robotics firm Stanley Robotics has appeared, with around 8 percent of the European radical novelties in this field since then. The French aerospace and defence corporation Safran is also an important frontier innovator, with 15.38 percent of total EU radical novelties in 2020, but with a large reduction in 2023.

Figure 9: Radical novelties in AI by entity (EU, 2019 – 2023)

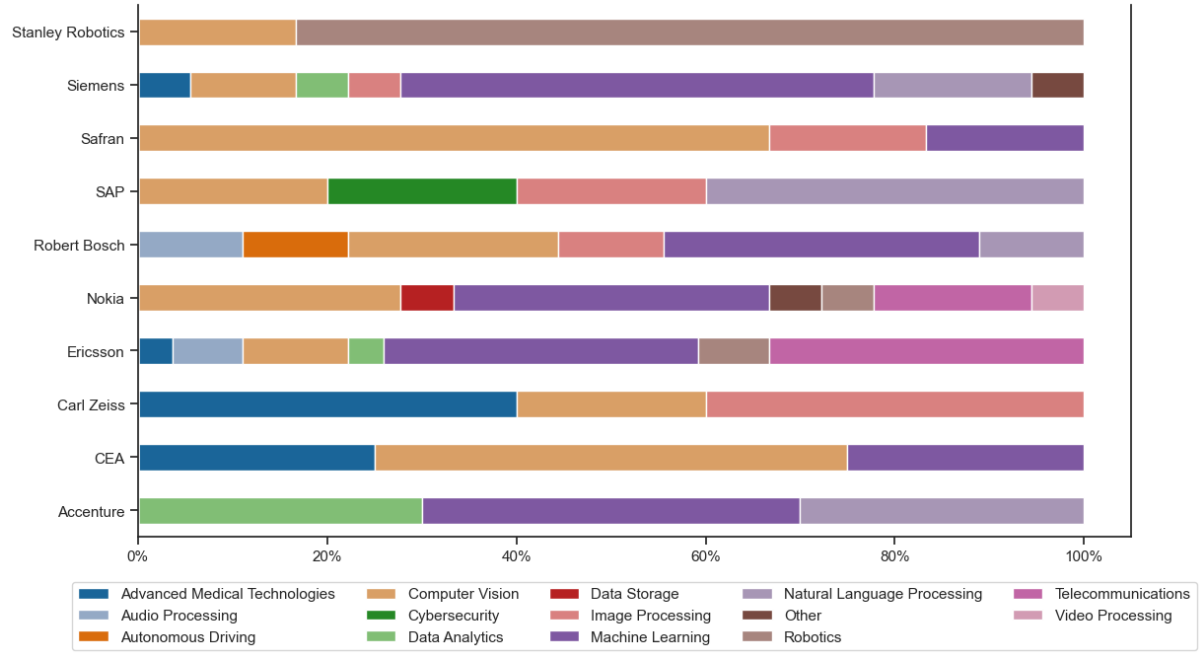


Source: Bruegel based on WIPO.

A distinguishing feature of European innovation in AI is its relatively small concentration in advanced manufacturing and robotics, except for Stanley Robotics (Figure 10). This is particularly surprising given the EU's long-standing comparative advantage in high-end manufacturing. Some firms also specialise in 'machine learning', notably Siemens (53.34 percent), Bosch (33.34 percent), Ericsson (33.34 percent), Nokia (33.34 percent) and Accenture (40 percent). Carl Zeiss and the French research organisation *Commissariat à l'énergie atomique et aux énergies alternatives* (CEA) are innovating in 'advanced medical technologies', although the absolute number – only five and four radical novelties, respectively – is small. Accenture and SAP, major providers of business services, are also innovating in 'natural language processing', with shares of 30 percent and 40 percent of radical novelties in this field, respectively.

A large fraction of European AI innovation is also driven by the EU's two major telecommunication firms, Ericsson and Nokia. Both firms have invested in AI-driven optimisation of network performance, energy efficiency and reliability, which requires capabilities in 'machine learning' (in our data with 33.34 percent and 33.34 percent, respectively) and 'telecommunications' (33.34 percent and 16.67 percent) more generally. Both firms also innovate in 'computer vision' (11.11 percent and 27.28 percent). Finally, the French defence corporation Safran also focuses on the processing of visual data, namely 'computer vision' and 'image processing'. This is not surprising given the firm's capabilities in automated target recognition and ground and air surveillance.

Figure 10: EU frontier innovators and their related subfields (AI)

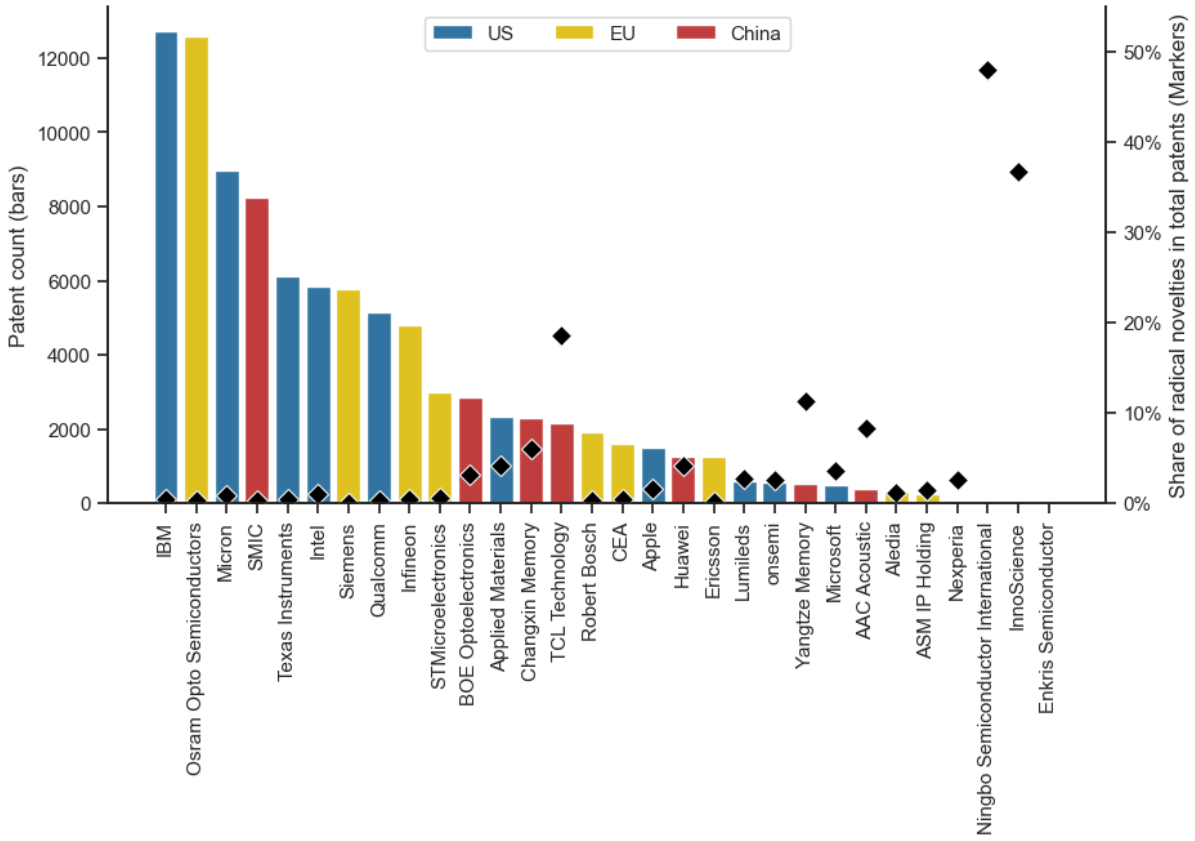


Source: Bruegel based on WIPO.

4.2 Semiconductors

We now move to our second critical technology, semiconductors. Figure 11 shows the raw patent counts in relation to the shares of radical novelty of frontier innovators in the three regions under observation. One striking feature is how many European firms are among the entities with the highest raw patent counts, represented by the bars. These include Bavarian optoelectronics firm Osram, Siemens, Infineon and Franco-Italian chip firm STMicroelectronics. Well-known semiconductor incumbents from the US also feature prominently in frontier innovation, including IBM, Micron, Intel and Texas Instruments. Chip manufacturer SMIC leads patenting for China, but only 0.29 percent of its patents are considered radically novel. Generally speaking, the share of radical novelties in total patents is low for large incumbent firms and usually does not exceed 1 percent. Some exceptions, however, are visible. Of the patents filed by Chinese consumer electronics giant TCL Technology, 18.58 percent fall under our definition of radical novelty. Changxin and Yangtze Memory Technology have shares of 6.12 percent and 11.38 percent, respectively. We now take a deep dive into each region separately, starting with China.

Figure 11: Patent count and share of radical novelties by entity (semiconductors)



Source: Bruegel based on WIPO.

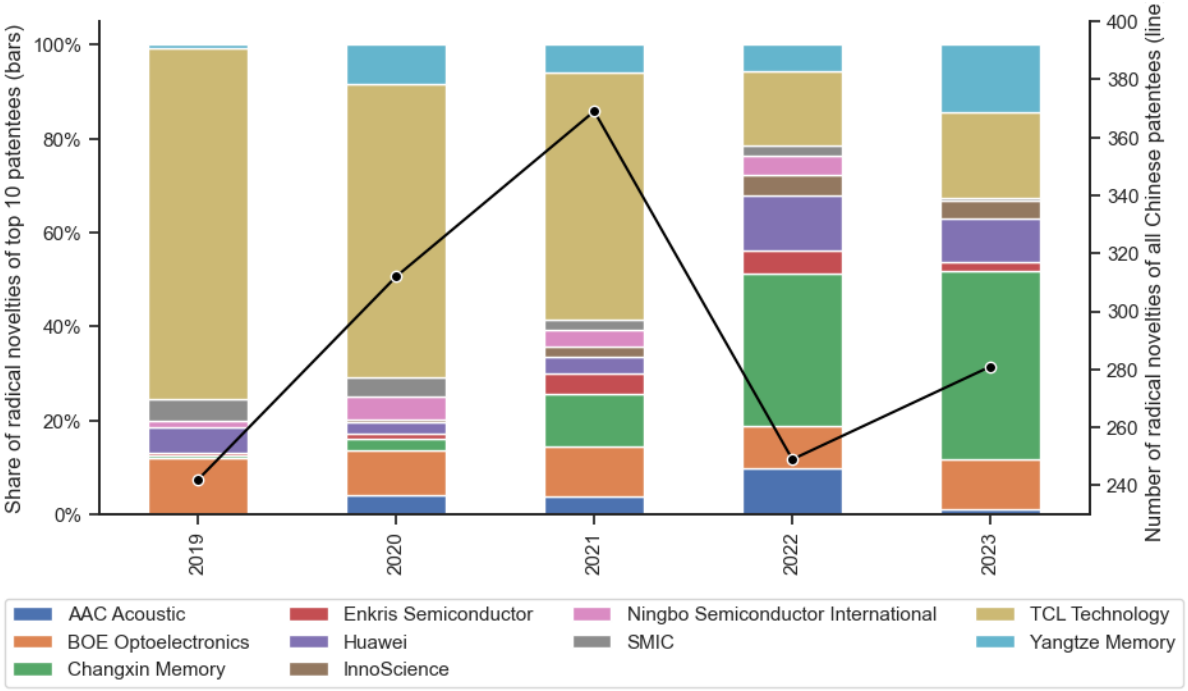
Figure 12 shows the frontier innovators across the period of observation in China. As a general trend, the importance of China's previously most innovative firm, TCL Technology, has diminished, from a share of 74.83 percent in 2019 to a mere 18.13 percent in 2023. Since 2022, memory technology and chip fabrication have become more important[7], which is represented by Changxin Memory (CXMT) and Yangtze Memory (YMTC), two of China's fastest-growing semiconductor manufacturing firms. Both have benefitted from investment by China's Big Fund in the past. CXMT – founded in 2016 as a private firm – received $724.18 million from the Big Fund in 2020 as part of a $2.38 billion deal with 13 co-investors (Pitchbook, 2024). Similarly, YMTC was founded by state-owned Tsinghua Unigroup in 2016 with an initial investment from the Big Fund, although the exact amount remains undisclosed. CXMT specialises in DRAM, while YMTC focuses on NAND Flash chips[8]. The visible

[7] Memory technology has traditionally presented a critical starting point for countries that aim at building a competitive semiconductor industry. Compared to logic-chip manufacturing, memory chips can be produced on mature 10–20nm nodes and do not require the high design complexity of logic chips or cutting-edge equipment for manufacturing. The market is also highly commoditised and firms rely less on brand reputation. Hence, entry barriers into the industry are generally lower. Once human capital in memory-chip manufacturing is accumulated, firms can then transition into the fabrication of more advanced logic chips. Both Taiwan and South Korea have followed such a path. All in all, the large share of radical novelties by Chinese firms in chip manufacturing and the fact that such innovation stems from companies that have been supported by China's semiconductor funds, sheds some light on the question of whether this industrial policy is working. A cost-benefit analysis of these policies, given their massive cost, is clearly beyond this paper's scope.

[8] YMTC reached the technology frontier in 2019 when it announced the development of a 64 layers 3D-NAND. Its latest breakthrough came in 2023, when a 232-layer 3D NAND chip was discovered in a consumer device. See *Tech Insights*, 'China Does It Again, A NAND Memory Market First', undated, https://www.techinsights.com/blog/china-does-it-again-nand-memory-market-first.

progress of CXMT and YMTC is a positive signal for the effectiveness of China's support projects (Semiconductor Big Funds). The data also reveals frontier innovators with lower shares of radical novelties, including Huawei, Ningbo Semiconductor International, Enkris Semiconductor and InnoScience. SMIC, while filing a large number of patents, almost disappeared from the ranks of the frontier innovators in 2023. Whether this is the result of US export controls is an intriguing question, but beyond the scope of this paper.

Figure 12: Radical novelties in semiconductors by entity (China, 2019 - 2023)



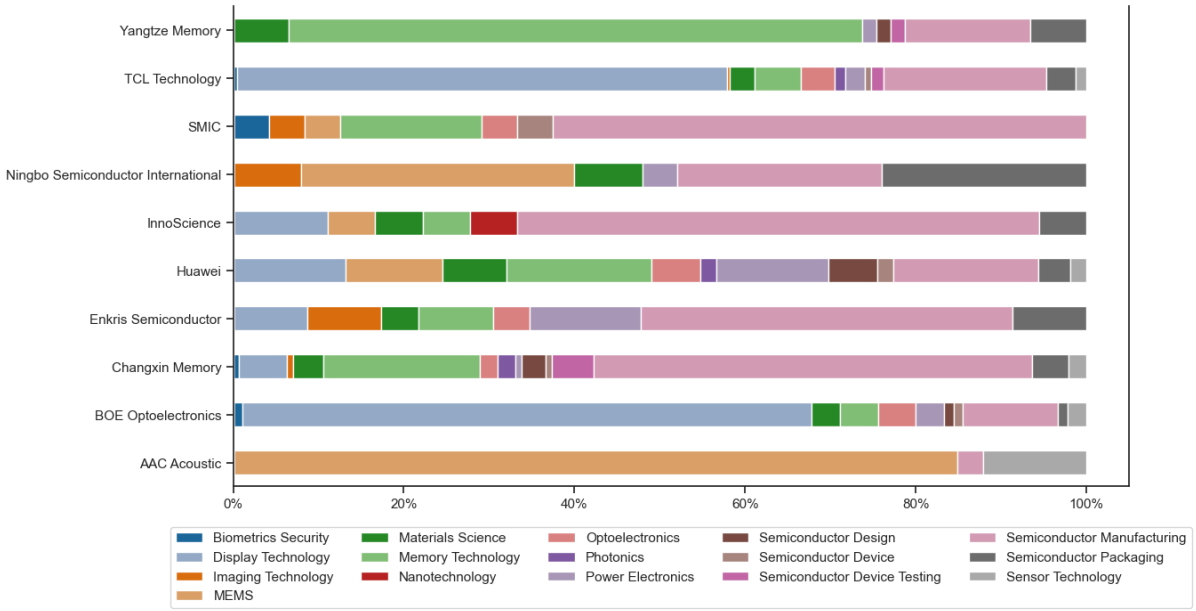
Source: Bruegel based on WIPO.

Looking at the subfield specialisation of these entities reveals further details (Figure 13). The two optoelectronics giants BOE Optoelectronics and TCL Technology are mostly focused on 'display technology', with lower shares in 'semiconductor manufacturing' (11.12 percent and 19.06 percent, respectively). Huawei, despite accounting for a smaller share of China's overall chip innovation, is highly diversified in its patented novelty portfolio, focusing on 'display technology' (13.21 percent), 'MEMS' (11.32 percent), 'memory technology' (16.99 percent), 'power electronics' (13.21 percent), 'semiconductor manufacturing' (16.99 percent) and 'semiconductor design' (5.66 percent). CXMT and YMTC, not surprisingly, focus on 'memory technology' and 'semiconductor manufacturing', although CXMT has a higher share in the latter than the former. SMIC, while accounting for a small share of radical novelties in general, has focused on 'semiconductor manufacturing', with 62.5 percent of its total radical novelties in this field.

Among the frontier innovators are also a few specialised firms, such as Shenzhen-based AAC Acoustic, which focuses on microphones and haptic feedback devices for consumer electronics and smart wearables, with 84.85 percent of its radically novel patents in 'MEMS'. Finally, InnoScience and Enkris are among the few firms dedicated exclusively to the production of specialised gallium nitride (GaN) chips. This is reflected in Enkris's concentration of novelties in 'semiconductor manufacturing' (43.48 percent) and even more for InnoScience. GaN chips are a semiconductor class that can handle higher temperatures, voltages and frequencies than silicon-based chips. They expand the possibility frontier of radar systems and satellite communication systems

for military purposes and also increase the efficiency of data centres and fast chargers (Shivakumar *et al*, 2024). InnoScience has been sued by German semiconductor firm Infineon[9] and US-based Efficient Power Conversion Corporation[10] for IP infringement.

Figure 13: Chinese frontier innovators and their related subfields (semiconductors)

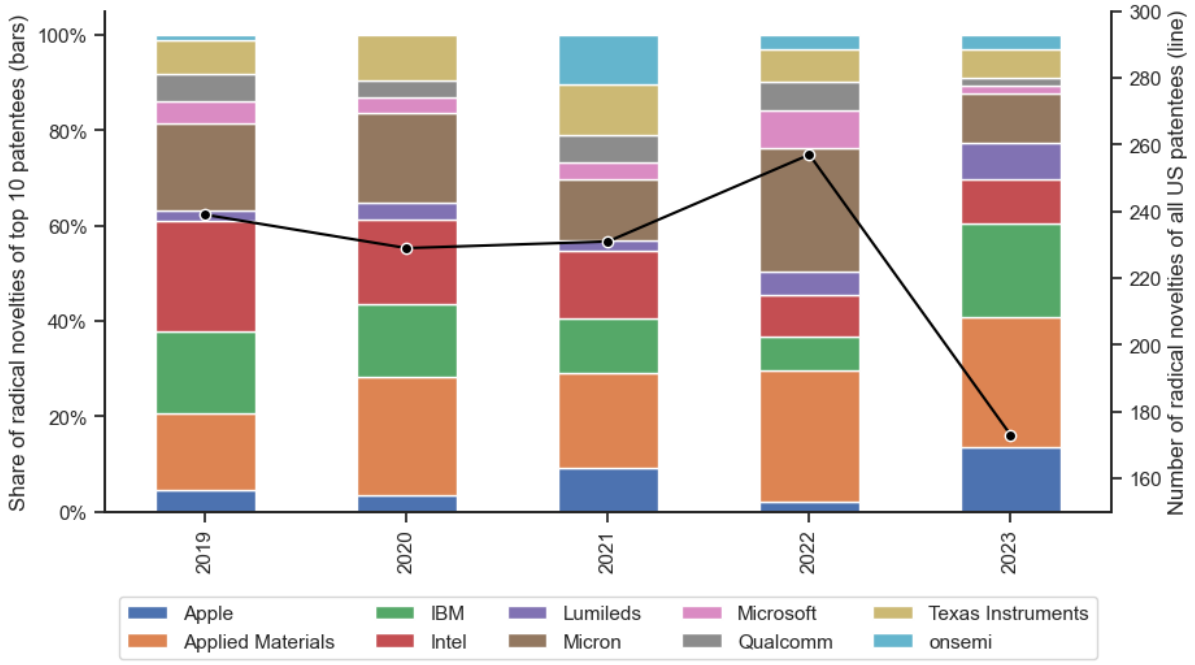


Source: Bruegel based on WIPO.

We now move to the United States, the country in which semiconductors were first commercialised at large scale. As can be seen from the line graph in Figure 14, the annual number of novelties in semiconductors hovers around 240 to 260, with a sharp drop in 2023. This is lower than the average number of radical novelties by Chinese entities, but we show in the next section that US firms specialise in subfields with higher value-added. Among the frontier innovators in our sample are well-known global players in the semiconductor ecosystem, including IBM, Intel, Applied Materials, Micron, Texas Instruments and Qualcomm. Intel has lost share of radical novelties, dropping from 22.99 percent in 2019 to 9.09 percent in 2023. Over the same period, IBM and Applied Materials gained ground, reaching shares of radical novelties of 19.70 percent and 27.27 percent respectively in 2023[11]. Micron, Apple and Texas Instruments also have consistently strong presences, with shares of between 5 percent and 20 percent annually. Microsoft, Lumileds, onsemi and Qualcomm account for smaller shares of radical novelties. Generally speaking, innovation stems from large incumbent firms.

[9] Michael Shapiro, 'Infineon Accuses Rival of Copying Gallium Nitride Technology (1)', *Bloomberg Law*, 14 March 2024, https://news.bloomberglaw.com/ip-law/infineon-accuses-rival-of-copying-gallium-nitride-technology.
[10] Christopher Yasiejko, 'California Firm Defends Key Chip Patents From Chinese Rivals (2)', *Bloomberg Law*, 17 July 2024, https://news.bloomberglaw.com/ip-law/california-firm-defends-key-chip-patents-from-chinese-rivals.
[11] As patents are published at most 18 months after being filed, this drop might be COVID-19-induced.

Figure 14: Radical novelties in semiconductors by entity (US, 2019 - 2023)



Source: Bruegel based on WIPO.

In line with the fact that the US dominates the more R&D-heavy upstream segments of the global chip ecosystem, many firms, including Qualcomm, IBM, Intel, Apple and Micron, have significant shares of radical novelties in 'semiconductor design' (Figure 15). However, the striking feature of US frontier innovators is that they generally tend to be diversified in their portfolios. In some cases, this reflects a high degree of vertical integration, most notably for Micron and Intel. Both firms design and then manufacture parts of their semiconductors in-house. In other cases, the diverse patent portfolios reflect the increased trend towards co-development of the design and related downstream activities (such as manufacturing and packaging), in particular for special-purpose or new, cutting-edge frontier chips[12].

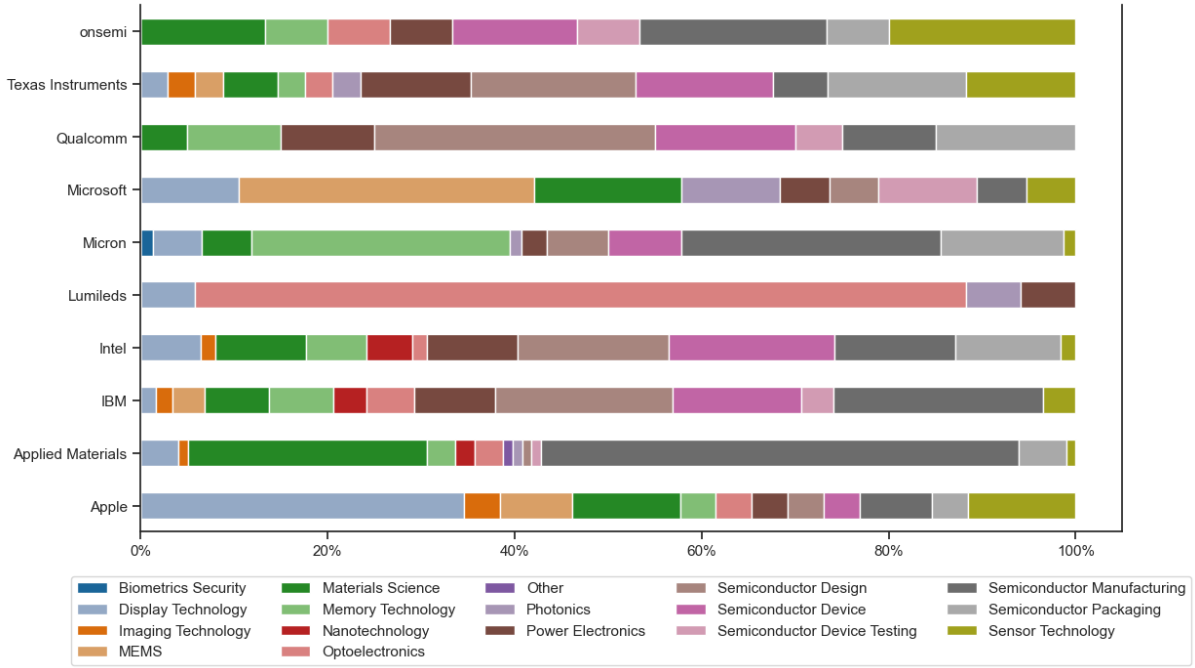
For instance, while it is not surprising that Apple has generated 34.16 percent of its radical novelties in 'display technology', it covers almost the entire value chain from 'semiconductor design', 'semiconductor manufacturing' and 'material sciences' to 'semiconductor packaging'. Similar patterns are noted with IBM and Qualcomm, which also have significant shares in 'semiconductor manufacturing' (22.73 percent and 10 percent, respectively) despite the fact that the two firms outsource the fabrication of their designs and other downstream activities to firms including TSMC, GlobalFoundries and Samsung. IBM, for example, has been active in developing EUV photoresist.

While diversification is apparent, a few specialised firms exist among the frontier innovators as well. While exact numbers are not available, Applied Materials is a key supplier of semiconductor manufacturing equipment for the fabs of global chip manufacturers such as Intel, Micron, TSMC and Samsung. In our data, Applied Materials holds more than three quarters of its novelties in 'semiconductor manufacturing' (52.02 percent) and 'materials science' (25.51 percent). Finally, Lumileds, which has slightly increased its overall share among the frontier

[12] Boston Consulting Group, 'Advanced Packaging Is Radically Reshaping the Chip Ecosystem', 20 May 2024, https://www.bcg.com/publications/2024/advanced-packaging-is-reshaping-the-chip-industry.

innovators in recent years, is highly specialised in 'optoelectronics', the subfield which accounts for 82.35 percent of its radical novelties.

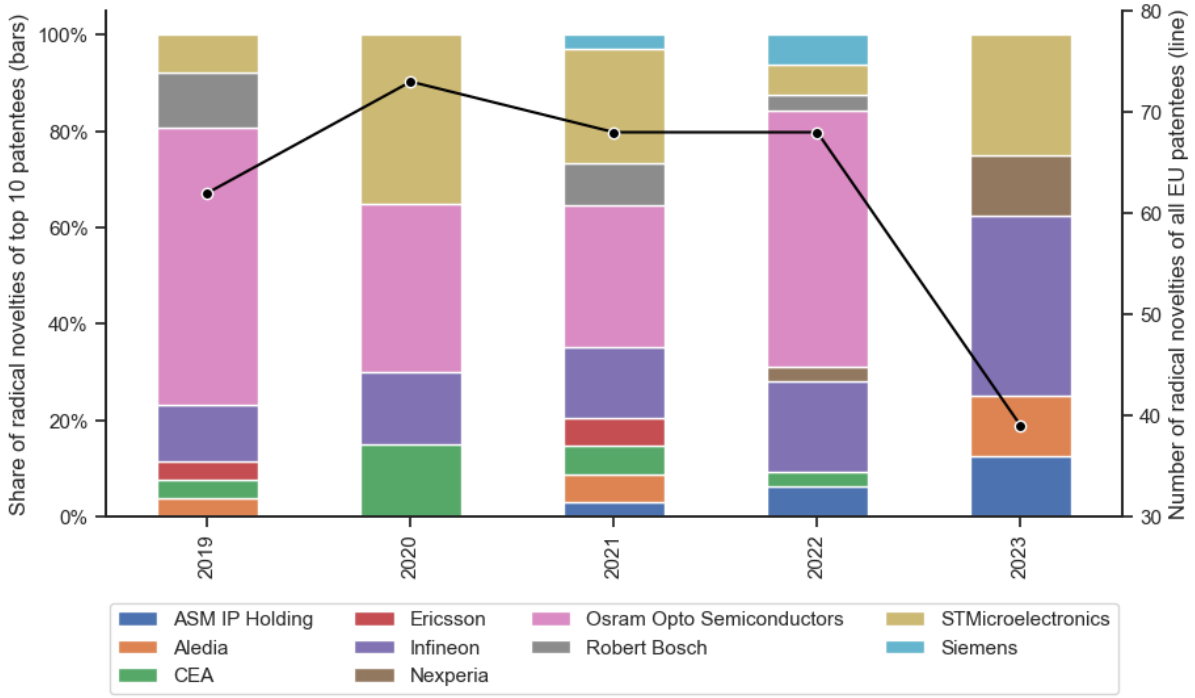
Figure 15: US frontier innovators and their related subfields (semiconductors)



Source: Bruegel based on WIPO.

Finally, moving to the EU, Figure 16 shows the evolution of radical novelties for the EU's frontier innovators. While EU entities appear dominant in the raw patent count, the number of novelties is quite low, with only about 70 per year. When compared to the US company landscape, novelties patented by EU firms are more concentrated around a few large players, notably Infineon, STMicroelectronics and Osram Opto Semiconductors. In 2019, Osram accounted for 57.69 percent of all novelties, but dropped out of our subset in 2023. STMicroelectronics is consistently present, with its share fluctuating between 6.25 percent and 35 percent. At the same time, Infineon rose up the ranks from 11.54 percent in 2019 to 42.86 percent in 2023. All other companies hold rather small shares. Similar to the situation in the US, the overall number of novelties in our data dropped for the EU in 2023, to 68, down from 39, largely driven by Osram Optoelectronics. In 2022, the firm published 17 novelties but disappeared from our sample in 2023.

Figure 16: Radical novelties in semiconductors by entity (EU, 2019 – 2023)

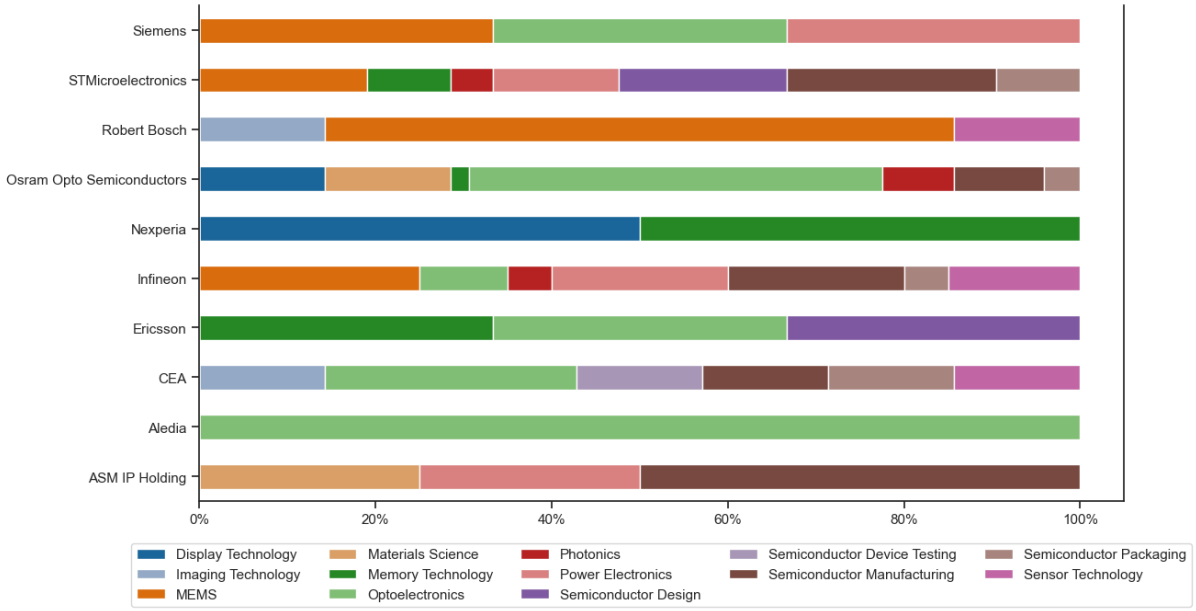


Source: Bruegel based on WIPO.

With regards to the subfield specialisations of the frontier innovators, the EU is focused on 'MEMS' and 'Optoelectronics', in which several firms have a strong presence (Figure 17). Most of these firms derive substantial parts of their revenues from the automotive industry. For instance, Osram Opto Semiconductors made €1.1 billion (40.74 percent of its total revenue) from its automotive lighting segment in 2023, mostly from LED and lasers for vehicle lighting and driver-assistance systems. Our data shows that 46.94 percent of its radical novelties fall under 'optoelectronics'. Another major innovator is Infineon, which is one of Germany's major automotive suppliers and is specialised in automotive semiconductors, which accounted for €8,242 million or 50.54 percent of its revenue in 2023. This is reflected in its portfolio of radically novel patents that reach 40 percent in 'sensor technology' and 'MEMS'. Bosch also specialises in the two fields, with 14.29 percent of novelties in 'sensor technology' and 71.43 percent in 'MEMS'. Not surprisingly, given its proximity to the Mercedes and Porsche HQ in Stuttgart, Bosch is also focused on the automotive industry. In 2023, it derived 61.52 percent of its revenues from its 'mobility solutions' segment.

Finally, STMicroelectronics is another strong innovator operating in various fields, deriving $6.7 billion (34.7 percent) of its revenues from its automotive segment, alongside analogue chips and MEMS (24.4 percent) and microcontrollers (39.9 percent). Based on our results, it is the only major EU chip firm with a highly diversified innovation portfolio, holding a presence in 'semiconductor design' (19.05 percent), 'MEMS' (19.05 percent), 'semiconductor packaging' (9.52 percent) and 'memory technology' (9.52 percent).

Figure 17: EU frontier innovators and their related subfields

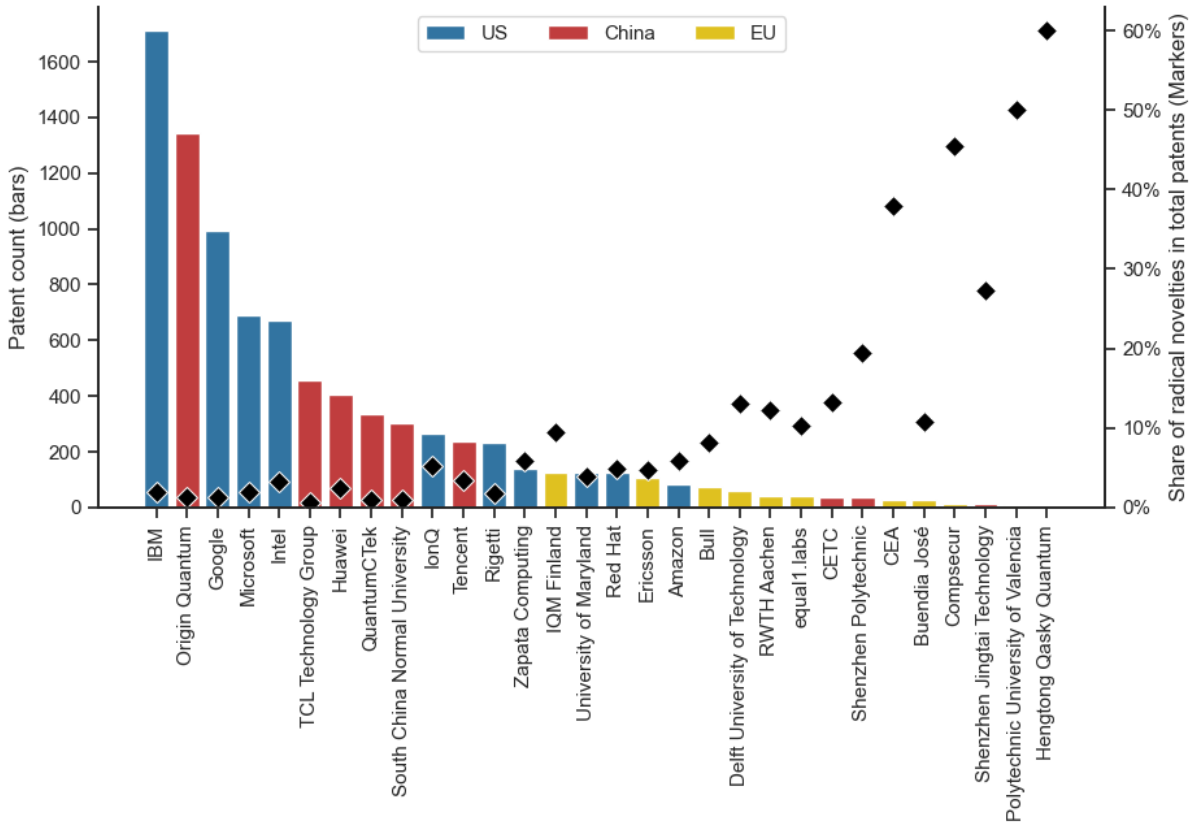


Source: Bruegel based on WIPO.

4.3 Quantum computing

The last of the three technologies covered by our analysis is quantum computing. As Figure 18 shows, the patent count is dominated by Chinese and US technology giants. Not surprisingly, IBM, Google, Microsoft and Intel are among the most active US patentees. On the Chinese side, Origin Quantum is taking the lead, with smaller numbers claimed by TCL and Huawei. Two significant features of the data are striking. First, unlike in AI and semiconductors, for frontier innovation in quantum computing, universities and dedicated research labs play crucial roles, despite not filing as many patents as large technology incumbents. Second, while the latter file large numbers of patents, the share of radical novelties in total patents is significantly higher for universities and start-ups, many of which are European, such as IQM Finland and Equal1.Labs. In what follows, we examine each region separately.

Figure 18: Patent count and share of radical novelties by entity (quantum computing)



Source: Bruegel based on WIPO.

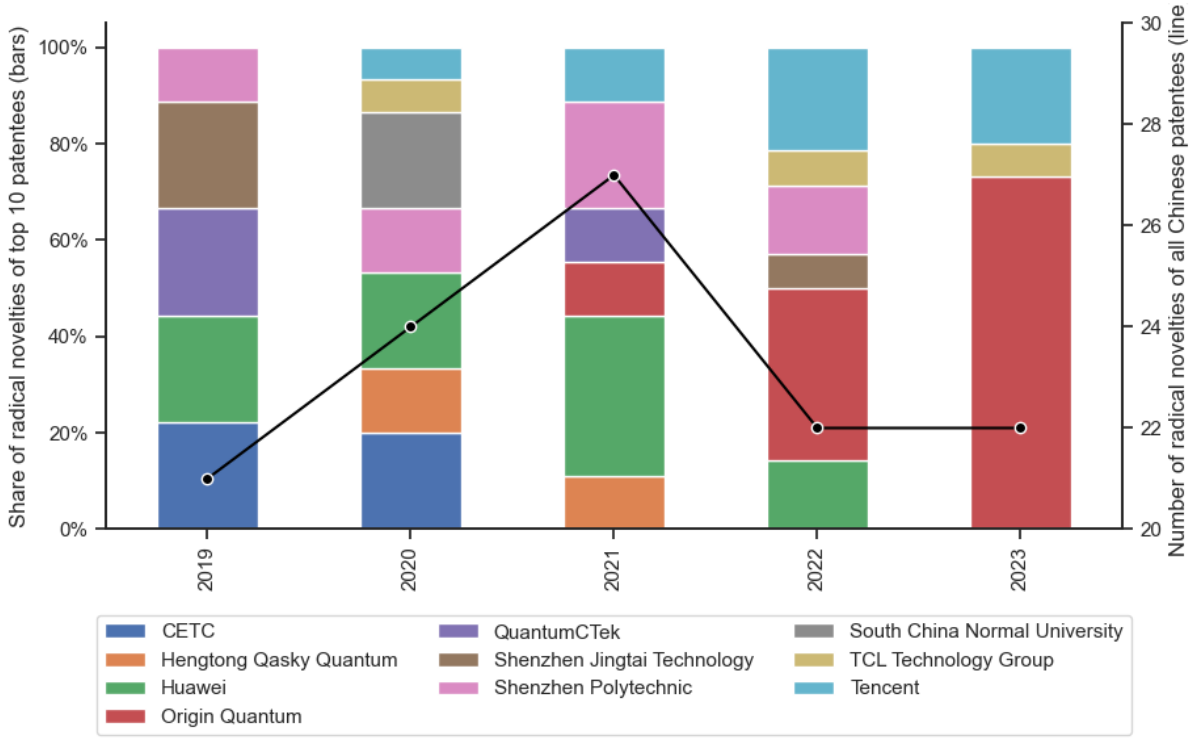
The evolution of quantum computing innovation in China has been relatively slow, with a peak in the number of radical novelties in 2021 (27) and a decline since then to barely 21 (Figure 19). The smaller number of novelties is in line with the relatively scarcer research funds available for quantum compared to AI. However, the recent pick-up in quantum research, given the need for faster, more efficient computer support for AI, should have led to an increase in the number of novelties, which is not the case for China. According to the distribution of radical technologies we find in our dataset, Chinese innovation in quantum computing is dominated by several large players, most notably Huawei, Origin Quantum and, more recently, Tencent. Several of the smaller innovators are universities and research institutions, including the state-owned CETC, the South China Normal University and Shenzhen Polytechnic.

Two of the main innovators, QuantumCTek and Origin Quantum, are located in Hefei, which is often viewed as a model city for local government-guided development. The city has developed into a cluster for firms across various parts of the quantum computing supply chain[13]. Origin Quantum has become the largest quantum computing innovator, with a 78.51 percent share of radical novelties in 2023, up from zero in 2020. In January

[13] *The Economist*, 'An unlikely tech cluster exemplifies China's economic vision', 5 August 2023, https://www.economist.com/finance-and-economics/2023/08/05/an-unlikely-tech-cluster-exemplifies-chinas-economic-vision.

2024, Origin Quantum announced the introduction of Origin Wukong, a 72-qubit quantum computer[14]. The other Hefei-based firm in our sample, QuantumCTek, was founded in 2009 and produces hardware and software for quantum secure communication. In July 2022, it was selected as one of the 10,000 Little Giants, an extensive government programme to foster the most innovative industry suppliers and equipment manufacturers (Brown *et al*, 2023; García-Herrero and Schindowski, 2024). Finally, Alibaba appears among the frontier innovators, although the firm officially scrapped its quantum computing segment in 2023[15], which means that it should have exited the market by now.

Figure 19: Radical novelties in quantum computing by entity (China, 2019 – 2023)



Source: Bruegel based on WIPO.

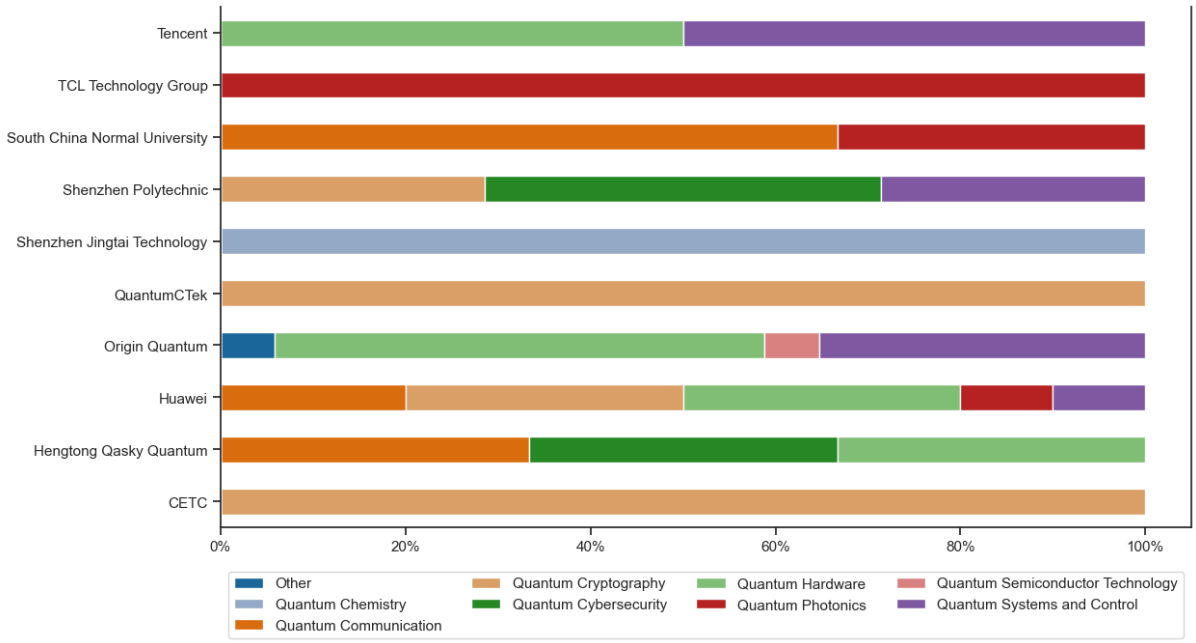
Figure 20 displays the subfields in which Chinese quantum computing firms are active. Huawei, as the largest innovator, has a strongly diversified quantum innovation portfolio, including 'quantum communication', 'quantum cryptography', 'quantum hardware' and 'quantum photonics'. Origin Quantum is focused on the physical components of quantum computing, with 'quantum hardware' and 'quantum systems and control' accounting together for 88.23 percent of its radical novelties. QuantumCTek, the other Hefei-based firm, is focused mainly on 'quantum cryptography' and 'quantum communication', with shares of 83.34 percent and 16.67 percent, respectively. Tencent is also focused on the physical aspects of quantum computing, namely 'quantum hardware' and 'quantum systems and control', while Shenzhen Polytechnic focuses on 'quantum

[14] *Quantum Zeitgeist*, 'China Quantum Computer 'Origin Quantum': Superconducting Quantum Computer has 72 Qubits in Boost for Chinese Technology', 7 January 2024, https://quantumzeitgeist.substack.com/p/china-quantum-computer-origin-wukong.
[15] Matt Swayne, 'Reports: China's Alibaba Shuts Down Quantum Lab', *The Quantum Insider*, 25 November 2023, https://thequantuminsider.com/2023/11/25/reports-chinas-alibaba-shuts-down-quantum-lab/.

cryptography', 'quantum cybersecurity' and 'quantum systems and control', with shares of 28.57 percent, 42.86 percent and 28.57 percent, respectively.

Generally speaking, the data highlights China's multifaceted quantum computing landscape. Chinese innovators are active in many fields at the same time, instead of carving distinct niches. Hardware producers such as Origin Quantum, Tencent, Shenzhen Polytechnic and Alibaba are complemented by firms specialising in 'quantum communication', 'quantum cryptography' or a union of those, among which are CETC, Huawei, Hentong Quasky Quantum and QuantumCTek. In recent years, however, as reflected by the dominance of Origin Quantum and Tencent, China's innovative dynamism in quantum computing has shifted to its physical aspects. These are generally considered the most critical but challenging aspects of quantum computing innovation because of the difficulties of maintaining the superposition of the quantum system (dubbed 'coherence'), the key necessary condition for operating a quantum computer (NAS, 2019).

Figure 20: Chinese frontier innovators and their related subfields (quantum computing)



Source: Bruegel based on WIPO.

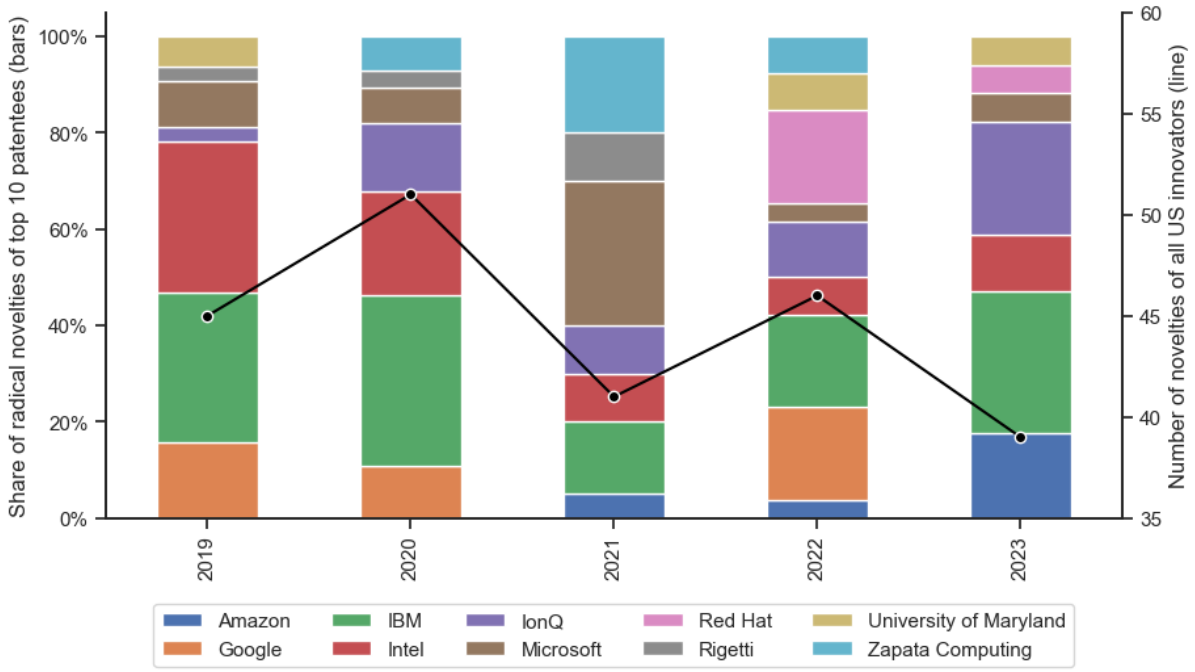
In terms of the evolution of quantum computing innovation in the US (Figure 21), among the top ten quantum computing innovators are well-known technology firms such as Intel and IBM, which hold major shares of radical novelties. IBM clearly stands out as the most innovative frontier firm and has consistently accounted for a share between 30 percent and 50 percent. This is not surprising given that IBM reached a global milestone in the evolution of quantum computing with the introduction of the Quantum System One in 2019, the first commercial circuit-based quantum computer[16]. Intel's share decreased from 40 percent in 2019 to a still formidable 16 percent in 2023.

[16] Rosalie Chan, 'IBM unveils the world's first quantum computer that businesses can actually use to solve previously impossible problems', *Business Insider*, 13 January 2019, https://www.businessinsider.com/ibm-unveils-ibm-q-system-one-the-first-commercial-quantum-computer-2019-1.

A few newcomers are also noticeable. Among the innovators with growing shares is IonQ, founded in 2015 to produce hardware for trapped-ion quantum computing. According to IonQ's official communication, its core technology is licensed from the University of Maryland, close to which IonQ is based, and which also appears independently among the frontier innovators. The two founders have a decade-long history of fundamental research in the field, highlighting the symbiotic relationship between universities and start-ups, for which the US has traditionally been famous (Mowery and Sampat, 2005). IonQ became the first publicly traded pure-play quantum computing firm in 2021[17].

Another entry into the quantum computing market is Zapata Computing, founded in 2017 by a team of Harvard scientists, and focused on the intersection of quantum computing and generative AI. The examples of IBM and Intel on the one hand, and Zapata Computing and IonQ on the other, reflect well the nature of the emerging quantum computing industry in the US. Innovation plays on both the well-known strength of large US technology incumbents and the nexus between university-based research and start-up creation.

Figure 21: Radical novelties in quantum computing by entity (US, 2019 – 2023)



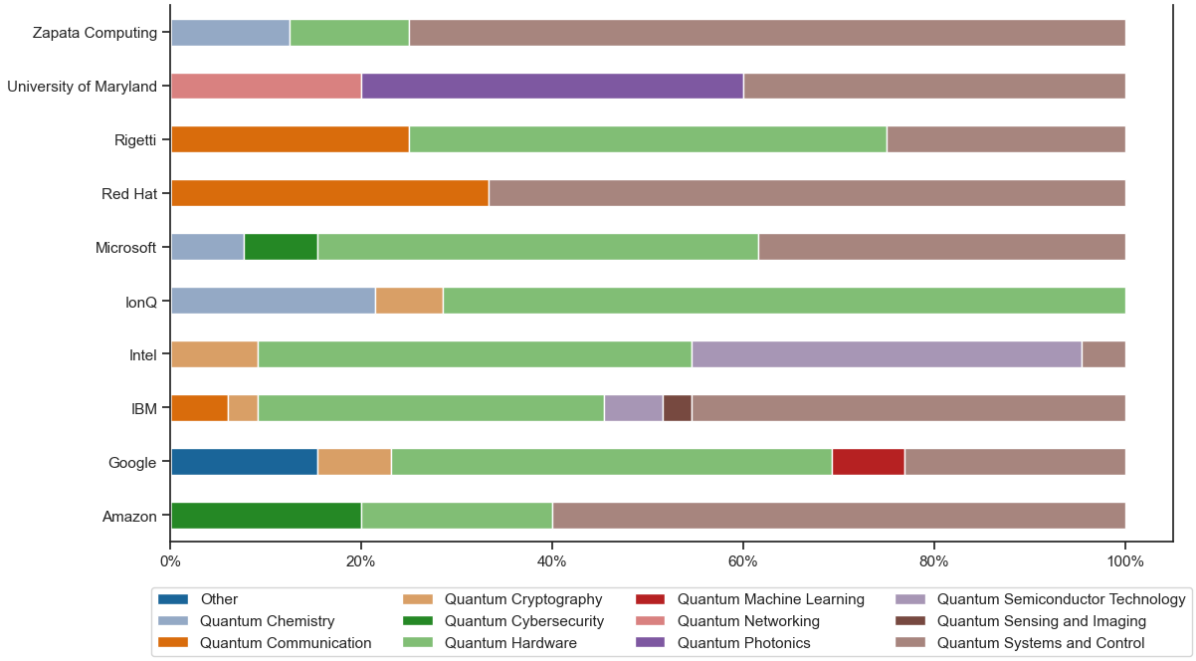
Source: Bruegel based on WIPO.

In terms of subfields, the top ten US innovators focus mainly on the physical components of quantum computing, with all key firms having a significant share of their radical novelties in either 'quantum hardware' or 'quantum systems and control' (Figure 22). Since the overall advancement of quantum computing depends on quantum hardware and control systems, the amount of frontier innovation in these areas reflects the US's leadership in quantum computing more generally.

[17] *Business Wire*, 'IonQ To Become The First Publicly Traded Pure-Play Quantum Computing Company', 8 March 2021, https://www.businesswire.com/news/home/20210308005321/en/IonQ-To-Become-The-First-Publicly-Traded-Pure-Play-Quantum-Computing-Company.

Still, some of the entities also specialise in specific aspects or applications of quantum computing. The University of Maryland holds a large share of radical novelties in 'quantum photonics' (22.22 percent) and 'quantum networking' (44.44 percent). Intel is innovating in 'quantum semiconductor technology', with a share of 38.30 percent of its radical novelties. The firm has made advances in developing silicon-based quantum computing processors, significant for the development of general-purpose quantum computers (Neyens *et al*, 2022). IonQ, Zapata Computing and, to a lesser extent, Microsoft are also innovative in 'quantum chemistry', the application of quantum mechanics to chemical systems. IBM subsidiary Red Hat holds one third of its radical novelties in 'quantum communication'. And finally, Amazon innovates in 'quantum cybersecurity', which accounts for a share of 20 percent of its novelties. Overall, the strong focus on quantum hardware and control systems reflects the intensity of the race towards the wide adoptability of quantum computers in the US.

Figure 22: US frontier innovators and their related subfields (quantum computing)



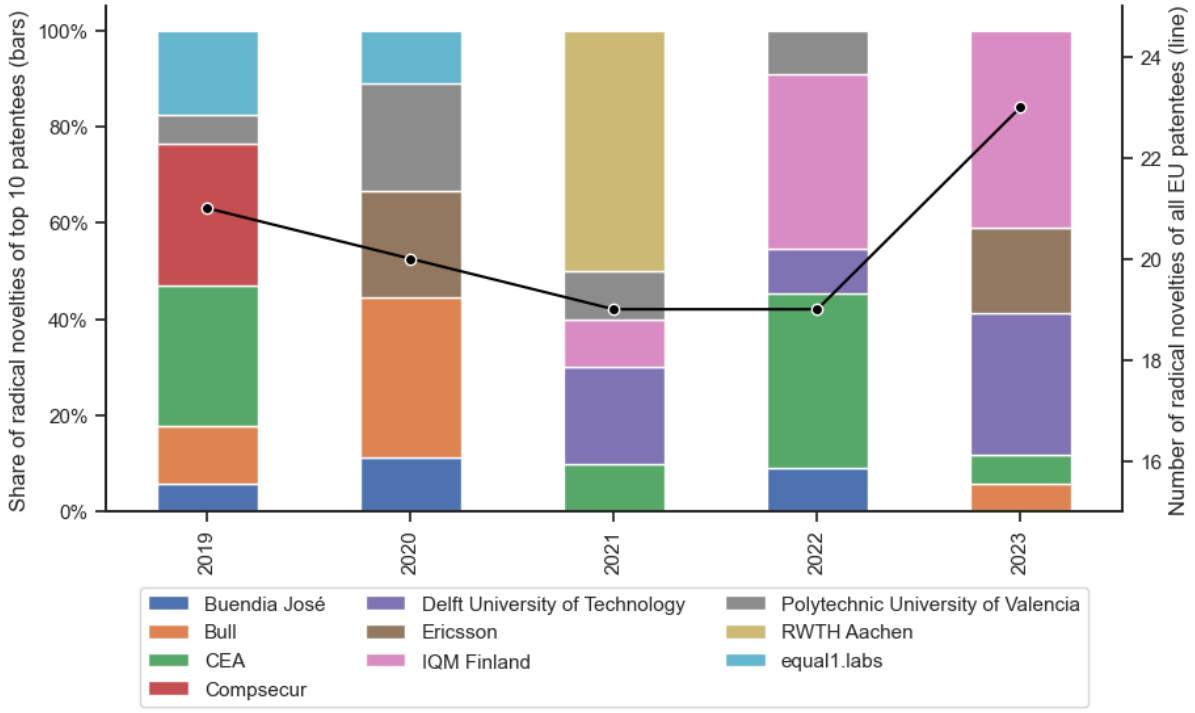
Source: Bruegel based on WIPO.

Moving to the EU, semiconductors are the critical technology in which Europe is closest to the US and China. As Figure 23 shows, the EU is almost on par with China in the number of radical novelties filed in quantum computing, reaching a total of 126 novelties during the period of observation compared to 130 from Chinese firms. Interestingly, the key European players in such innovation are (mostly public) research institutions and not companies like in the US, while China lies in between. In other words, a significant amount of the top innovation in quantum computing in the EU occurs outside of the commercial space.

For instance, one of the quickly growing innovators is the Delft University of Technology in the Netherlands, whose share of novelties among the top ten innovators in the EU rose from 15.79 percent in 2021 to 30.43 percent in 2023. Two Finnish firms are among the top innovators, including incumbent telecommunications firm Ericsson and the entrant firm IQM Finland, the latter founded in 2018 and now dominating radical novelties in European quantum innovation with shares of 30.77 percent and 30.43 percent in 2022 and 2023, respectively. Other firms include French state-owned enterprise Bull (now Atos) and the government-funded research

organisation *Commissariat à l'énergie atomique et aux énergies alternatives* (CEA), which jointly developed the supercomputer Tera 1000. Interestingly, some of the most relevant innovators, like Rhine-Westphalian Technical University Aachen (RWTH Aachen), have moved from being the largest producers of radical novelties in quantum to virtually disappearing.

Figure 23: Radical novelties in quantum computing by entity (EU, 2019 – 2023)



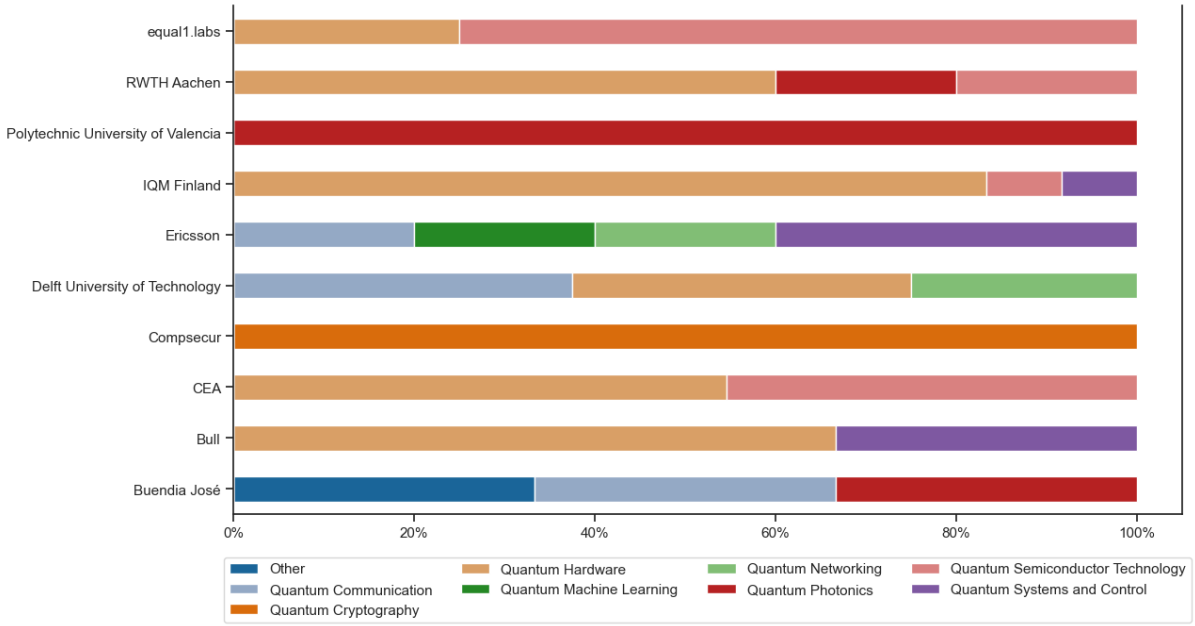
Source: Bruegel based on WIPO.

Similarly to the US, the EU's focus on innovation in quantum computing is strongly focused on 'quantum hardware' and 'quantum systems and control' (Figure 24). For instance, RWTH Aachen holds two thirds of its radical novelties in 'quantum hardware', and the rest with equal shares in 'quantum semiconductor technology' and 'quantum photonics'. Bull, HQS Quantum Simulations and IQM Finland are nearly entirely focused on the two subfields.

Next to innovators in quantum computing equipment, Ericsson and the Delft University of Technology hold fairly diversified novelty portfolios. Ericsson is innovating in 'quantum communication' (with 20 percent of its novelties filed there), 'quantum machine learning' (20 percent), 'quantum networking' (20 percent) and 'quantum systems and control' (40 percent). Although all these subfields are crucial for Ericsson's core business activities, the total amount of novel patents it has filed so far in quantum (5) remains small. Delft University of Technology innovates equally in 'quantum communication', with one third of its radical novelties in this subfield, and the rest falling into 'quantum hardware' (25 percent), 'quantum networking' (25 percent) and 'quantum semiconductor technology' (16.67 percent). Among the specialised firms, the French state-owned research institute CEA and Irish start-up Equal1 Labs focus on 'quantum semiconductor technology', with shares of 45.45 percent and 75 percent within their respective novelty portfolios. Compsecur innovates exclusively in 'quantum cryptography', with all of its five radical novelties in this subfield. The Polytechnic University of Valencia filed all of its eight radical novelties in 'quantum photonics'. What is remarkable about European

quantum computing is how geographically dispersed it is. The top-ten innovators are from eight different EU countries.

Figure 24: Chinese frontier innovators and their related subfields (quantum computing)



Source: Bruegel based on WIPO.

5 Conclusions

Competition in critical technologies is attracting increasing attention not only because of their foundational nature for other types of innovation but also because of their importance in the technological competition between the US and China. To better understand which countries and companies are leading in these technologies, we use the methodology developed by García Herrero *et al* (2025) to identify radical novelties (ie novel patents) in AI, semiconductors and quantum computing. Their findings pointed to the US dominating AI, at least in terms of radical novelties, followed by China and with the EU in a far distant third position. However, China appears to have come up with more novel patents in the semiconductor sector than the US, although US firms dominate the highest value-added sectors, such as design. As for quantum, the US clearly leads frontier innovation, even more than for AI. China and the EU follow behind and, unlike for AI, the EU is on par with China in terms of radical novelties.

In this paper, we look into the entities that are patenting the radical novelties and find that they are quite different across geographies. In the US, technology companies dominate the three critical technologies and with very high concentration in a few names. In fact, IBM, Intel and Microsoft rank in the top 10 in terms of the numbers of novel patents in each of the three critical technologies. In China, only Huawei produces a similarly large number of radical novelties for all three critical technologies (chips, quantum and AI). In Europe, the French Alternative Energies and Atomic Energy Commission (CEA) and Ericsson are both in the category of triple frontier innovator. Frontier innovators in the field in which the EU competes more equally, namely quantum, are mostly research centres and not companies like in the US. China lies somewhat in between in all three domains, although with fewer companies for quantum.

Finally, looking at how companies have evolved in terms of patents in the subfields of AI, semiconductors and quantum computing, China is found to have increased relentlessly, not only the number of critical novelties but also their relevance when looking at performance across subfields. For example, in the subfield of quantum computing, China has shifted from 'quantum cryptography' and 'quantum cybersecurity' to the more technologically challenging fields of 'quantum hardware' and 'quantum systems and control'. Similarly, in semiconductors, China has moved away from innovating predominantly in 'display technology' to defining the technology frontier in 'memory technology' and 'semiconductor manufacturing'. An interesting finding is the relatively more volatile presence of frontier innovators for China, with some key innovators disappearing from the list while new ones suddenly appear at the top of the list. This could be related to Chinese companies having been included in the US entity list, but more research is needed to test this hypothesis.

All in all, for AI, US tech companies remain dominant in terms of critical (patented) novelties for 'machine learning', 'natural language processing', 'cybersecurity' and 'generative AI'. China focuses mostly on the processing of visual data and robotics, two fields that are technologically closely related and that have military applications. The EU's stronger field, namely quantum computing, is dominated by research centres (mostly public) and is also very diverse and geographically dispersed, which might be a disadvantage in terms of commercialisation. In semiconductors and AI, EU companies patent far fewer radical novelties than Chinese or American companies. This is even the case in subfields in which the EU used to have a longstanding comparative advantage, such as robotics.

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Appendix

US top patentees company list

Abbreviation	Full name	Website
Adobe	Adobe Inc.	www.adobe.com
Amazon	Amazon.com, Inc.	www.amazon.com
Apple	Apple Inc.	www.apple.com
Applied Materials	Applied Materials, Inc.	www.appliedmaterials.com
Google	Google LLC	www.google.com
IBM	International Business Machines Corporation	www.ibm.com
Intel	Intel Corporation	www.intel.com
IonQ	IonQ	ionq.com
Lumileds	Lumileds	http://www.lumileds.com/
Micron	Micron Technology, Inc.	https://www.micron.com/
Microsoft	Microsoft Corporation	https://www.microsoft.com/
Nvidia	Nvidia Corporation	https://www.nvidia.com/
onsemi	ON Semiconductor Corporation	https://www.onsemi.com/
Oracle	Oracle Corporation	https://www.oracle.com/
Qualcomm	Qualcomm Incorporated	https://www.qualcomm.com/
Red Hat	Red Hat, Inc.	https://redhat.com/
Rigetti	Rigetti Computing, Inc.	http://rigetti.com/
Texas Instruments	Texas Instruments Incorporated	https://www.ti.com/
UOM	University of Maryland, College Park	https://umd.edu/
Zapata Computing	Zapata Computing Holdings Inc.	https://www.zapatacomputing.com/

China top patentees company list

Abbreviation	Full name	Website
AAC Acoustic	AAC Technologies Holdings Inc.	https://www.aactechnologies.com/
Autel Robotics	Autel Robotics Co., Ltd.	https://www.autelrobotics.com/
Baidu	Baidu, Inc.	https://www.baidu.com/
BOE Optoelectronics	Beijing BOE Optoelectronics Technology Co., Ltd	https://www.boe.com/en/
BOE Technology Group	BOE Technology Group Co., Ltd.	https://www.boe.com/en/
ByteDance	ByteDance Ltd.	https://www.bytedance.com/en/
CETC	China Electronics Technology Group Corporation	https://en.cetc.com.cn/
Changxin Memory	ChangXin Memory Technologies	https://www.cxmt.com/en/
CloudMinds Robotics	CloudMinds Technologies Co. Ltd	https://cloudminds.com/
Enkris Semiconductor	Enkris Semiconductor Inc.	https://en.enkris.com/
Hengtong Qask	Hengtong Qasky Quantum Inf. Research Institute Co., Ltd.	https://www.hengtonggroup.com/
Huawei	Huawei Technologies Co., Ltd.	https://www.huawei.com/en/
InnoScience	InnoScience Technology Holding Co., Ltd.	https://www.innoscience.com/
Ningbo Semiconductor	Ningbo Semiconductor International Corporation	https://www.nsemii.com/#/index
Oppo	OPPO Guangdong Mobile Telecommunications Corp., Ltd.	https://www.oppo.com/en/
Origin Quantum	Origin Quantum Computing Technology (Hefei) Co., Ltd.	https://originqc.com.cn/
Ping An	Ping An Insurance (Group) Company of China, Ltd.	https://group.pingan.com/

QuantumCTek	National shield quantum	https://www.quantum-info.com/
Jingtai Technology	Shenzhen Jingtai LCD Technology Co., Ltd	https://www.xtalpi.com/
Shenzhen Polytechnic	Shenzhen Polytechnic	https://english.szpu.edu.cn/
SMIC	Semiconductor Manufacturing International Corporation	https://www.smics.com/en/
SCNU	South China Normal University	https://english.scnu.edu.cn/
TCL Technology	TCL Technology Group Corp.	https://www.tcltech.com/en
Tencent	Tencent Holdings Ltd.	https://www.tencent.com/en-us/
UBTECH Robotics	UBTECH Robotics Inc.	https://ubtrobot.com/
Yangtze Memory	Yangtze Memory Technologies Co., Ltd.	https://www.ymtc.com/

EU top patentees company list

Abbreviation	Full name	Country	Website
Accenture	Accenture plc	Ireland	https://www.accenture.com/
Aledia	Aledia	France	https://www.aledia.com/en/
ASM IP Holding	Advanced Semiconductor Materials	Netherlands	https://www.asm.com/
Bull	Bull SAS	France	http://www.bull.com/
Carl Zeiss	Carl Zeiss AG	Germany	https://www.zeiss.com/
CEA	French Alternative Energies and Atomic Energy Commission	France	https://www.cea.fr/
Compsecur	CompSecur sp.	Poland	https://compsecur.pl/
DUT	Delft University of Technology	Netherlands	https://www.tudelft.nl/en/
equal1.labs	Equal1	Ireland	https://www.equal1.com/
Ericsson	Ericsson Limited	Sweden	https://www.ericsson.com/en
Infineon	Infineon Technologies AG	Germany	https://www.infineon.com/
IQM Finland	IQM Quantum Computers	Finland	https://www.meetiqm.com/
Nexperia	Nexperia	Netherlands	https://www.nexperia.com/
Nokia	Nokia Corporation[	Finland	https://nokia.com/
Osram Opto	Osram Opto Semiconductors GmbH	Germany	https://ams-osram.com/
Polytechnic University	Valencia Polytechnic University	Spain	https://www.upv.es/index-en.html
Robert Bosch	Robert Bosch GmbH	Germany	https://www.bosch.com/
RWTH Aachen	RWTH Aachen University	Germany	https://www.rwth-aachen.de/
Safran	Safran S.A.	France	https://safran-group.com/
SAP	SAP SE	Germany	https://www.sap.com/
Siemens	Siemens AG	Germany	https://www.siemens.com/
Stanley Robotics	Stanley Robotics	France	https://www.stanley-robotics.com/
STMicroelectronics	STMicroelectronics NV	Switzerland	https://www.st.com/

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